I. C. 6689

March, 1933

DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

INFORMATION CIRCULAR

RECEIVED
APR 10 1933
O. S. U. LIBRARY

DEVELOPMENT OF SAND AND GRAVEL DEPOSITS

BY

J. R. THOENEN

I.C. 6689
March, 1933.

INFORMATION CIRCULAR

DEPARTMENT OF COMMERCE - BUREAU OF MINES

DEVELOPMENT OF SAND AND GRAVEL DEPOSITS[1]

By J. R. Thoenen[2]

CONTENTS

Page
Introduction 2
Factors affecting development 3
  Economic features 3
  Physical characteristics of the deposit 3
  Character and thickness of overburden 4
  Physical characteristics of the material 5
  Thickness of the deposit 6
  Disposal of waste 7
  Plant capacity 7
  Capital available 8
  Effect of treatment processes on development 8
  Delivery of material to the plant 8
  Washing 9
  Elimination of impurities 9
Development as a coordinating agent 9
  Relation of excavation site to plant location 10
  Relation of treatment to excavation methods 11
  Storage and waste disposal 12
Summary 12
Development methods and their application to various types of deposits . 12
Types of deposits 13
Definitions 13
Bank deposits 15
  Straight cuts 16
  Circular or elliptical cuts 22
  Elevated bank deposits 28
  Thick bank deposits 29
  Hydraulic development 30
Pit deposits 33
  Dry pits 35
  Wet pits 38
Marine Deposits 41
  River deposits 41
  Lake and ocean deposits 42
Typical examples of development methods 42
Bibliography 46

---

[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6689."

[2] Senior mining engineer, U. S. Bureau of Mines.

INTRODUCTION

This circular is the second of a series presenting methods employed in solving the technical problems encountered in the production of sand and gravel. The first paper[3] discussed the methods used in prospecting and exploration. This one deals with the problems involved in bringing a raw prospect to the production stage and considers the various methods of development and the factors affecting that development. Later publications are planned to present and discuss methods of recovery and treatment.

The recovery of sand and gravel from natural deposits and their preparation for market involve a progressive sequence of operating steps or processes. Each step or process presents its own peculiar problems which require different angles of mental approach, methods, and tools, but all are more or less dependent on the step or process which precedes or follows.

Development is defined as the process of preparing a deposit for exploitation with the object of recovering its contents for sale or use. Prior to the beginning of actual development, however, considerable thought and study must be given to the results obtained from exploration for the purpose of deciding the methods that are to be used in recovery and treatment of the material in the deposit (14),[4] for the whole development program depends upon what method of operation or type of equipment is used.

The decision as to the method of operation and type of equipment to employ is governed largely by the information obtained by prospecting and exploration. It will also depend upon a number of other factors totally without the scope of the prospector's field, such as the production capacity desired, the market to be served, and the capital available. Therefore, a discussion of any one step in the sequence must involve and recognize the effect of preceding or subsequent steps.

Study of exploration results for the purpose of determining the method of attack on the deposit and the treatment of the material does not, strictly speaking, come under the designation of development, however, in this circular the term "development" is used in a somewhat broader sense and includes this preliminary study and planning in order to show the interrelation between the process steps and their effect on the ultimate plan which fixes the method of development to be followed.

It is the object of this circular, first, to point out those items that affect the method of development; second, to show the importance of properly coordinating the sequence of operations in planning for development; third, to present the various methods of development as applied to different types of deposits; and fourth, to present typical examples of actual practice.

---

[3] Thoenen, J. R., Prospecting and Exploration for Sand and Gravel: Inf. Cir. 6668, Bureau of Mines.

[4] Figures in perenthesis refer to the bibliography at the end of this circular.

FACTORS AFFECTING DEVELOPMENT

Economic Features

Totally aside from the technical problems presented in sand and gravel recovery but of equal or possibly even greater importance are the many economic problems involved. These may be such as to condemn a property which offers ideal operating conditions from a purely technical point of view. For instance, a deposit may be of such a nature as would allow production and preparation of suitable market material at a minimum of expense and yet be inaccessible for economic delivery to markets. Another deposit may be within reach of an attractive market, but be composed of materials which could not be economically treated to supply that market. It is not within the scope of this series of papers to discuss economic problems in detail. The author has pointed out these features in a previous publication,[5] and such items will be herein discussed only as they affect the development plan.

It will be assumed, then, that the location, size, and requirements of local and distant markets, as well as other economic factors, have been investigated and their effect on the operation discounted.

Physical Characteristics of the Deposit

The physical characteristics of the deposit present the first problems in devising a development plan. The surface topography will influence the type of operation necessary. If the deposit is elevated above the surrounding land surface it will require a different plan of operation than a deposit below the surface. Local topography may indicate a difference in the equipment to be used for recovering the sand and gravel from two deposits, even though they may be of the same general type. Alternative equipment affords a choice of several methods of development. Obviously a plan designed for mechanical shovel operation would not be suitable for cableway or dredge excavation, and vice versa.

The size and shape of the deposit will have a direct although possibly a minor effect upon the development plan. A small irregularly shaped deposit would ordinarily not lend itself to large scale development. Another deposit, small in volume, may be so self-contained and regular in shape as to warrant large-scale operation for production of a maximum tonnage in a minimum time. Small irregular shapes are not as common in dry-land deposits as in river bars, but when they do occur they should not be overlooked.

Long narrow deposits may be opened transversely to best advantage at one location while at another they must be developed parallel with the long axis. Local conditions will determine the procedure.

Occasionally gravel deposits will be found to dip sharply from the horizontal. A different method of development and operation will have to be used in such a place.

---

[5] Thoenen, J. R., Economics of New Sand and Gravel Developments, Econ. Paper 7, Bureau of Mines, 1929, 60 pp.

The proximity of the permanent ground-water level to the surface will largely determine the method of development of subsurface pits. Sand and gravel occurring in areas in which the ground water approaches the land surface often present opportunity for a wide choice of excavating equipment. In thin deposits which are otherwise ideal for operation by pump dredge the water level may have such a relation to the bottom of the gravel as to prohibit its use because of insufficient water to float the dredge. In other deposits this relation just as emphatically indicates the superiority of the dredge over other equipment (40).

Some deposits extending below ground-water levels have such irregular lower limits that a drag line or scraper would dig up so much deleterious material from the underlying stratum when mining the lower portion that their use would be prohibitive. Recourse must then be had to other types of machinery that can reach those irregular patches. If this item is not considered, much valuable material may be lost through a choice of the wrong type of equipment.

Development for one type of equipment will be unsuited for another. For instance, development for drag line or scraper operation will be quite different from that for dredges. Even different types of dredges will require different development programs. For example, a pump dredge may excavate and deliver material through pipe lines to a plant on land, while a clamshell or ladder dredge may deliver directly to barges to be towed to the land plant, or either type of dredge may be constructed to treat the gravel on the dredge itself, delivering finished material to be transferred to distribution yards or semifinished material for further treatment in the land plant (61).

Gravel under water may be developed for drag line, cableway, or dredge operation, but in each case the details of development will differ materially.

Character and Thickness of Overburden

One of the first undertakings of any operator of a land deposit is a study of the material overlying his commercial deposit. The removal or utilization of overburden presents problems which may tax the operator's ingenuity to the limit and may mean success or failure in his venture. On the other hand, stripping is sometimes inconsequential.

Under-water deposits in general have no stripping problems. At times, however, floods may bring down a quantity of undesirable material and completely cover a commercial deposit (7) (22). This material must be removed or the equipment shifted to another site. Where such conditions are apt to occur they must be considered in the plan of development in order that they may be met by building jetties to divert river currents or by other means (56).

Few land deposits, on the other hand, are devoid of overburden, although such overburden does not in many cases present operating difficulties. If the overburden is thin or of a sandy nature it may be feasible to disregard it entirely and send it to the treatment plant with the gravel. If thick or not easily removed by washing it must be stripped ahead of the gravel excavation.

Stripping may be either periodic (24) or concurrent with production of gravel. In either case it may be possible to use the same equipment for both stripping and gravel excavation (65). In some cases digging equipment is used for stripping during the winter or nonproductive seasons (59). In others the same equipment handles stripping when delays in plant or haulage equipment prevent mining. In others, provision is made in the operating cycle for alternate stripping and production (41). In still others different or identical types of equipment are used concurrently with one unit engaged in stripping and another in producing gravel.

The effect of stripping on production must always be carefully weighed in laying out the development program, in order that it may involve the least interference with production.

In some cases the overburden has a commercial value (19). Sometimes it may be sold during only certain portions of the year, and must be otherwise disposed of during the balance. In still other cases local laws require the replacement of top soil after removal of the gravel. When stripping is necessary, excavation must be carried on in two cycles; and other things being equal, the method employed in stripping affects the development plan. For instance, the development of a deposit stripped hydraulically will be entirely different from that of one stripped by mechanical equipment.

The extreme thickness of an unsalable overburden may render a deposit of otherwise commercial gravel worthless when the use of a certain method of stripping is contemplated; if another method of stripping is adopted, however, the results may be reversed.

Physical Characteristics of the Material

The material contained in sand and gravel deposits differs greatly. Some deposits contain an excess of bowlders requiring crushing and only a relatively small amount of sand (57). Typical examples are some alluvial-fan deposits of the West coast and the river deposits in the Pittsburgh area (19). Other deposits, and these are far more prevalent, contain an excess of sand. It is evident that plans for both excavation and treatment of material of such widely divergent characteristics will require different methods of development (48).

Still other deposits will be found to contain such quantities of deleterious materials as to require development methods entirely unlike those that would be employed for clean materials. As examples, a hillside deposit may contain such an excess of clay as to require a preliminary washing by hydraulic excavation. This changes the development plan from one for bench excavation by shovels to hydraulic washing and pumping. An under-water deposit may contain such an amount of river debris as to prohibit the use of any other than a clamshell dredge (7). Again, in some river operations the material excavated in a season's digging may be completely replaced by spring floods, thus permitting excavation from the same pit year after year from a stationary plant (45) (46). Development at such a deposit is obviously entirely different from that at places where portable river equipment is required.

On the one hand a large deposit may contain commercial material segregated in only certain portions or contain sand at one point and gravel at another (28). Such a deposit, though large in its aggregate extent, must be developed in small-scale separate units (64). Conversely a small deposit may contain material sufficiently uniform and clean to warrant large-scale development.

Gravel deposits may contain foreign material which must be removed in the treatment plant. This requires provision in the development plan for sufficient water to operate jigs or other separating machinery (63).

Often sand and gravel are more or less cemented by calcareous, silicious, or metallic exide materials (49). Many times this cementation extends throughout the entire thickness of the deposit. At other times it may exist in only thin layers or beds, but such beds may be so tightly cemented as to prevent penetration by pump suction or, if dry, by drag line, cableway, or even shovel excavation. Several instances are known where the gravel bank must be drilled and blasted ahead of even heavy shovel equipment (49), and in one instance, at least, submarine blasting ahead of a ladder dredge was contemplated.

Thickness of the Deposit

Thin deposits extending over wide lateral areas must be developed so as to provide easy access to an extended and rapidly changing working face. This requires a different type of attack and equipment from the thick, compact deposit. In thin deposits the digging equipment must be of lighter and more mobile construction, and the haulage equipment and track layout must be suited to rapid and frequent changes.

Thick deposits may require working more than one bench by the same or even different types of equipment. Even where a thick deposit is worked in one bench the methods of attack will differ greatly in different localities either because of topographic or other physical conditions or because of personal preferences for different types of equipment.

Bedded material in a thick deposit may require a different method of approach at one point than at another in the same deposit. Inclusion of lenses of waste material in the deposit may cause a change in method as excavation proceeds. These conditions must all be reflected in the development plan, which must be flexible enough to care for them.

The thickness of under-water deposits has a direct bearing on the type of dredge to be used. Some thin submarine deposits are more economically recovered by cableway or drag line than by dredge, even though there be abundant water to float a dredge.

Disposal of Waste

Waste in a gravel pit comes from two sources--overburden and an excess of some one or more sizes of processed material. In the one case it originates at the site of excavation, in the other at the plant. In both cases provision must be made for its disposal. Dumping space must be allocated where it will cause a minimum of future inconvenience and yet where it can be reached with a minimum of expense. A dump suitable for overburden may be entirely out of the question for plant waste and vice versa. Periodic sale of either overburden or plant waste may require that the dump be placed so as to allow easy recovery of its contents. For the same reason it may be inadvisable to mix overburden and plant waste. This will require two dumps or a segregation of the materials in the one dump.

The scheme of development must consider these factors with all their ramifications, else difficulties will arise in future operations. Many dumps located without proper study during development have had to be removed or rehandled at considerable expense.

Plant Capacity

There is probably no one feature having a more profound effect on development than that of the quantity of material which must be handled daily. Development of any deposit for small-scale production will have little relation to that for large-scale operation. There will be a difference in the amount of stripping required, in the capacity and operation of digging equipment, in the haulage equipment, and in the treatment plant. Also, an entirely different method of excavation and treatment may be used. As an example, the operation of a small wayside pit may find excavation by scrapers and tractors delivering to a log washer sufficient to recover, wash, and eliminate an excess of fine sand. A large plant on the same site would require shovels, locomotives, cars or other conveying equipment, and an elaborate washing, screening, and possibly classification plant.

Development for a temporary wayside pit will be much less exacting than for a large permanent plant. Herein the importance of development differs from prospecting and exploration. The small operator has just as much need for proper exploration as the large operator. Development for the wayside pit requires only temporary provision for a relatively short period of operation and need not be concerned over the life of the deposit or equipment.

Plant capacity, however, is usually determined by economic factors entirely aside from technical problems. When capacity is once determined by those economic features then the plant equipment becomes a technical problem which the development program must solve.

Capital Available

The amount of capital available for construction and operation is, of course, of vital importance. Many plants have been started on veritable shoestrings and by careful management built up into large profitable operations. The fact remains, however, that an operator with only a few thousand dollars is in no position to embark on a development program involving the construction of a large operating unit such as a ladder dredge.

In all cases the plan must be made to fit the capital available. If it does not do this the result is inevitable failure.

Effect of Treatment Processes on Development

In the preceding discussion some of those factors pertaining to production have been enumerated and their effect on the development plan indicated. The method and equipment used in treating material and preparing it for market also must be considered in preparing the development plan.

Delivery of Material to the Plant

The method of delivery of the material to the plant is influenced by surface topography and will depend largely on the type of excavating equipment used. In most cases the first step in handling material at the plant is to elevate it to a considerable height from which it may pass through the various processing steps by gravity. In a few cases where material requires the elimination of excess fine sand or clay a preliminary washing is arranged for prior to this initial elevation, in order to conserve power by decreasing the amount of material elevated. Provision must then be made for disposal of this waste product.

The transfer of material from the bank or pit to the treatment plant presents problems which have been solved in a variety of ways by different operators. In selecting a haulage system much will depend upon the experience and personal preference of the operator. In dry surface deposits one operator will depend upon auto-truck haulage from pit to plant, another will install locomotives and cars, a third may prefer a conveyor-belt system (39), while a fourth may use hydraulic pumps and pipe lines. The same is true of wet or dry subsurface pits, but with the addition of a cableway excavator delivering directly to the plant (20). Even in under-water deposits the transfer of material may be effected in many ways such as by cableway or dragline excavation directly to the plant (20), by tug boat and barges, aerial tramways (32)(66), or by pumping through pipe lines (34).

Proper consideration of the internal plant haulage problem is of prime importance in any plan of development. A deposit on a hilltop may require the establishment of highway or railway grades to bring the material to the treatment plant on the abutting plain. On the other hand, such deposits often offer a minimum of difficulty in this respect in that the material may be lowered by gravity to the plant. In any case haulage at a hilltop or hillside deposit will be entirely different from that at one entered from the base of the hill.

Haulage from a depressed pit presents a different set of problems in that the material must be elevated to the plant, thus requiring more power.

Provision must be made for whatever system of haulage is used and the development plan must be laid out accordingly.

Washing

Material discharged from pipe lines may or may not require further fresh water for washing. Material delivered by trucks, cars, drag line, or cableway will invariably require wash water. The provision of adequate sources of water and its delivery to the plant in the required quantity is as much a part of the development program as the preparation of the deposit itself.

Elimination of Impurities

Some gravels require only washing to prepare them for market. Others require the elimination of foreign matter, which may necessitate the use of special machinery, such as jigs (63).

The elimination of impurities from sand and gravel is essentially a problem of treatment. However, preparation for the method of treatment and disposal of waste products is essentially a problem of development, and must be adequately considered in any development program.

Where sands are prepared for special markets special machinery may be required, and provision should be made in the development program to accommodate this treatment.

DEVELOPMENT AS A COORDINATING AGENT

The primary purpose of development of any deposit is the preparation of that deposit for exploitation. A secondary but equally important purpose is the planning and arrangement of operations in such manner and sequence as will require the minimum expenditure of money, labor, and power in recovering the material, transferring it to the treatment plant, preparing it for market, and either delivering it to that market or making it easily accessible for such delivery as needed. In this second phase preliminary planning plays an important part in development by correlating the information derived from exploration with the plans for the several subsequent operating steps.

A proper exploration program will have developed information as the size, shape, and thickness of the deposit, the character and disposition of the materials in the deposit, the position of ground water, the topography of the terrain, the source and abundance of available water, and the location with respect to shipping facilities. The development plan will utilize this information to devise the method of attack and the method of treatment, and finally to coordinate all factors into the most feasible and economical plan of operation giving consideration to all local features.

Original from THE OHIO STATE UNIVERSITY

The last item involves a number of factors which it will be well to discuss at this point.

Relation of Excavation Site to Plant Location

The relation of the excavation site or point of attack on the deposit to the location of the treatment plant may or may not be of considerable importance (54).

In the case of river, lake, or ocean deposits where the material is excavated and delivered to the plant without preparation by the excavating unit the length of haul to the plant may become a serious problem. Ordinarily in such operations, as the work progresses the distance between the digger and plant increases. If the material dug contains little waste this is of small concern, but if an appreciable proportion of this material must be discarded at the treatment plant the operation is handicapped by the extra expense of hauling it over an increasing distance. The question then arises as to how far this material can be transported or how much can be handled for less money than it would take to erect a treatment plant on the excavating unit itself. As an example, in several river operations with which the author is familiar the amount of fine sand taken from the river bed far exceeds the gravel removed. In such cases the operator has rightly decided it is cheaper to install a treatment plant on the dredge to eliminate this fine material and ship only commercial material to the shore plant.

A similar decision may be reached in cases where the location of a shore plant is such that there is no place for disposal of this waste material.

In land plants the problem becomes even more complicated. For instance, a deposit may be so situated and have such surface topography as to require economical attack from the north side while shipping facilities are located to the south. The development plan must correlate these divergent factors and balancing one against the other decide whether to attack on the north and haul to a treatment plant at the south; to place the treatment plant at the north adjacent to the point of attack and haul only finished material to the shipping point; or to attack from the south adjacent to the plant and shipping point, but under adverse conditions for excavation (37)(51).

A hilltop deposit may be so situated that access to it would be difficult and costly by highway or railway grades. The problem then becomes one of whether the plant will be placed at the deposit and finished material lowered by gravity to the base of the hill; the plant placed at the base and pit-run material lowered to it; or the plant placed on the slope of the hill with pit-run material delivered to it at the top and finished material removed from it at the base. All three types of procedure have been justified by local conditions and are in practice.

In a flat deposit exploration may have shown the upper portion of the pit to contain a clean coarse gravel free from clay and the lower part to be more or less contaminated with fine sand and clay seams. In such case it might

Original from THE OHIO STATE UNIVERSITY

be advantageous to remove the top by shovel, and the lower portion by dredge, drag line, or cableway (19)(26)(43)(44).

If it is decided to follow the shovel by dredge or drag line, the plant may be located so as to provide a minimum haul, inasmuch as some intermediate transfer equipment must be used in both cases. This may be equally true with the cableway. However, it may develop that the plant can be located at a point where the cableway can deliver directly to it and thus save intermediate haulage while excavating the lower portion of the deposit (20).

Concentration of excavation site, plant, and shipping point in close proximity has the advantage of arranging a compact operation with a minimum of interplant handling (23)(37). Such concentration may require less construction capital at the start and be justified on that ground alone, although greater ultimate economies might have been enjoyed by placing the point of attack at greater distance. Often the small operator with limited means is justified in starting operations after a development plan which would be considered poor practice for large-scale development.

These few examples will illustrate the need for properly planning the relation between plant site and point of attack in the development scheme and also the coordinating agency of development between exploration and production.

Relation of Treatment to Excavation Methods

The method of treatment to be used in preparing sand and gravel for market will be influenced greatly by the physical characteristics of the material in the deposit. They may also be a deciding element in the selection of the excavating equipment. In fact in some installations the excavating method is designed to provide a preliminary step in the treatment process in addition to recovering the material from its natural position. For example, the local conditions may be such that a deposit may be worked equally well either wet or dry but a surplus of clay may cause the decision to swing to the wet method in order to provide a preliminary washing. In this way less equipment may be needed in the treatment plant and less power expended for providing wash water. If the dry method of excavation is used, additional washing machinery will be required in the plant. In many cases this is a serious consideration and it should not be overlooked in the development plan.

In those deposits containing an excess of fine sand or bowlders it is desirable to separate this excess material from the plant feed as early as possible (48). Where conditions permit, preliminary separation is made at the point of excavation. In so doing provision must be made in the pit or elsewhere for disposal of this material. In some localities excess bowlders are crushed and either sold as crushed gravel or mixed with the plant feed. The crusher may be a part of the field equipment in the pit or of the plant itself.

In those laterally extended but comparatively thin deposits containing segregations of various-sized materials a choice is sometimes possible between

Original from THE OHIO STATE UNIVERSITY

the erection of a central treatment plant to which separate excavating units send their product (28) and portable treatment units at each individual excavation point. These portable units in turn may be designed to produce a finished marketable product or they may only partially prepare the gravel and sand and send it on to a separate central plant for finishing. As an example, the portable plant may merely separate the sand from the gravel, returning the excess sand to the excavated pit and sending the balance to the central plant for sizing. Whatever operating scheme is chosen, the details should be worked out in the development stage.

Storage and Waste Disposal

In the majority of gravel plants no provision is made for storage of finished marketable material. The practice followed is to load this material directly into railway cars or other transportation equipment as fast as produced. In a growing percentage of plants, however, the finished material is sent to storage piles for later reclaiming and mixing, as the market requires. It will be obvious that a different development plan will be necessary for the two types of operation.

Waste disposal is a trying problem at many plants. In some, development is designed so that overburden, excess sand or bowlders, and plant waste sizes can all be dumped into the excavated pit. At others separate dumping space must be provided both for field and plant waste. The development plan must recognize this need and arrange for dumping space which will not interfere with future operations.

SUMMARY

It will be seen from the foregoing discussion that the development plan must consider a large number of operating details both as to their individual effect upon the sequence of operations and as to their combined effect in influencing the coordination of the several operating steps. Thus, while development in its restricted sense deals only with the preparation of the deposit for exploitation, it must in a broader sense encompass the causes, effects, and results of a variety of operating methods and equipment and by preliminary planning incorporate the whole into a smoothly working sequence of operationsdesigned to suit local conditions.

DEVELOPMENT METHODS AND THEIR APPLICATION TO VARIOUS TYPES OF DEPOSITS

The matter of development of an individual deposit is based on so many local contingencies that specific recommendations can not be made which will be found applicable in all instances. Were an engineer to confine his recommendations to a certain plan of development for a specific type of deposit he might get by without criticism in one or two instances, but very shortly he would encounter local conditions entirely at variance with such set plans. Therefore, in presenting the various methods of development in this paper, their application to the different types of deposit will be pointed

Digitized by Google Original from THE OHIO STATE UNIVERSITY

out in only a general way. Where more than one development plan is applicable to a certain type, alternative plans will be discussed. In this way it is hoped that the subject will be presented in such a manner that the reader may best apply the suggestions to his local conditions.

In discussing various methods of development it will be assumed that economic features and the correlation of operating steps have been given due consideration and that a general scheme has been worked out in advance. The discussion of the process of development as follows will then be confined to the restricted definition--the preparation of the deposit itself.

Types of deposits

From the viewpoint of the producer, deposits of sand and gravel fall into three general classes with five subdivisions, as follows:

1. Bank
2. Pit:
   a. Dry
   b. Wet
3. Marine:
   a. River
   b. Lake
   c. Ocean

This classification has been adopted by the United States Bureau of Mines in studying safety conditions and operating methods.

Definitions

Bank. A bank deposit is defined as one in which the elevation of the excavation floor is level with or above the surrouding land surface. Thus an open-cut in a hill or ridge which is entered from the plain at the base is a bank deposit. Likewise a similar cut entered part way up the slope of the hill is a bank. Bank deposits are usually operated dry, although in a few instances hydraulic methods are used. In no case, however, is the material dug from below the surface of a natural or artificial body of water.

Pit deposit: Dry.- A dry pit deposit is defined as one wholly below the level of the surrounding land surface, but in which the excavation floor is above the level of permanent ground water. The use of the modifying adjective "dry" refers only to the position of the deposit with relation to the groundwater level. Ordinarily dry pits are operated dry, but they may be worked by hydraulic methods. Excavation from a dry pit never occurs below the surface of a natural or artificial body of water.

Pit deposit: Wet.- A wet pit deposit is defined as one wholly below the level of the surrounding land surface in which the excavation floor is below the level of permanent ground water.

Original from THE OHIO STATE UNIVERSITY

Where gravel occurs in flat terrain a deposit may be operated as both a dry and wet pit. That portion below the land surface but above ground water may be removed in the first bench as a dry operation. Where the deposit is of exceptional vertical thickness more than one bench may be so removed. That portion of the deposit lying below the ground water, however, will be removed as a wet pit. It is not at all unusual to find the whole deposit excavated as a wet pit. In these cases digging from below the water surfaces caves the material above, and it is removed along with the lower portion.

In other cases one may find a combination of bank and wet-pit operation. When ground water is close to the surface at the base of the hill or bank, the material above is removed as a bank deposit and the lower portion extending below ground water is worked as a wet pit. Banks or dry pits in which the gravel is excavated by hydraulic methods and sluiced to a pump in a pit dug below water level are not classed as wet pits.

Marine deposits: River.- A river deposit is defined as one in which the gravel forms the bed, bars, or small islands between the natural banks of the river.

Deposits on islands of such size that they may be worked as dry or wet pits wholly within the island are not included in this definition. This confines river deposits to the area between its natural banks. In some instances the river banks themselves form commercial deposits. An operator excavating a bar or bed in a river may continue into the bank when it is reached. The extension of such an operation changes it from a river operation to a wet pit because shifting bars due to current and flood action do not occur in excavations extending beyond the line of the bank.

In cases where excavation is extended into a large island conditions may simulate those in river-bank extensions. These cases are not numerous but when they do occur they should be classed as wet pits.

It will be clear, then, that river deposits as defined, with the exception noted for large islands, invariably occur within the boundaries of the natural banks of the river.

Marine deposits: Lake.- Lake deposits are defined as those in which the material forms the lake bed or beach.

Marine deposits: Ocean.- Ocean deposits are defined as those in which the material forms the ocean bed or beach.

Lake and ocean deposits are similar except that one is in fresh and the other in salt water. This difference, in itself, presents diverse operating problems. In addition conditions such as tides, storms, etc., on the ocean present problems not encountered in any but the largest lakes. Because of these differing problems lake and ocean deposits are subdivided into two separate classes, although excavation operations are similar.

Inland extensions of excavations originating in lake or ocean beaches should be classed as wet pits, as in the case of extensions into river banks.

BANK DEPOSITS

Bank deposits of sand and gravel may be of either residual, fluvial, marine, lacustrine, or glacial origin. The residual flint or chert deposits occurring in low rounded ridges in the great plains area of the Middle West are typical of the first class. Alluvial cones and river terraces in mountainous areas, outwash plains of the central states, and the kames and eskers of the glaciated section represent fluvial or glaciofluvial formations; the coastal plain deposits of the eastern seaboard contain many bank operations; plants on the borders of Great Salt Lake and terraces of old glacial lakes present bank deposits of lacustrine origin; materials of purely glacial origin are represented in the deposits found in moraines scattered throughout the glaciated area.

Bank deposits present a great variation with regard to the thickness and character of both overburden and contained material, as might be expected from the differences in their origin.

These variations provide an interesting set of problems in preparing a development program. Two deposits in the same original formation may be operated differently due to local conditions and require different development plans. This emphasizes an earlier statement that recommendations as to the method of development of any type of deposit must be general rather than specific, leaving details to be worked out according to local requirements.

Bank deposits are usually worked dry, although in a few exceptions excavation has been carried on by hydraulic sluicing. The ordinary procedure is to remove the material in horizontal slices, but in some cases, owing to the great vertical thickness and elevated topography of the deposits, the gravel is recovered in sloping slices or troughs.

In the matter of equipment, power shovels are used in a large majority of banks, although drag-line excavators and cableway scrapers are much in evidence. There are also a few instances of hydraulic sluicing.

Where the overburden is thin and of a sandy nature it may often be disregarded entirely. On the other hand, heavy clay capping may require separate removal and even entirely separate and different equipment from that used in digging gravel.

In some cases even thin overburden must be removed separately because of the great amount of vegetable matter contained in roots and decayed foliage. This is particularly true where the deposit of gravel itself is comparatively thin and the ratio of overburden to sand and gravel correspondingly large.

The first step in preparing a bank deposit for development is the removal of surface vegetation in the form of trees, undergrowth, etc. This may be done by force account or by contract in which the contractor receives an agreed price per acre.

Original from THE OHIO STATE UNIVERSITY

The next step is the removal of overburden. This may also be done by force account or contract. If by contract the price is usually fixed at so much per cubic yard of material moved, although sometimes the price is set by the square yard or acre of surface stripped.

If the operation is a new venture and all the equipment that will be used in both stripping and digging gravel must be purchased, the physical characteristics of the deposit will have a decided influence upon the type of machinery bought and the size of the units.

If the equipment is brought in from another deposit which has been abandoned, or if it has been purchased secondhand, the development plan must be so arranged that operations will conform to the working limits of the equipment.

The first condition will allow a wide choice of equipment and method of operation. The second, although limited as to equipment, may even so admit of various methods of procedure. In the following discussion some examples are analyzed in which either the general physical conditions of the deposit are assumed or the equipment available is limited to certain types and sizes, or both.

Development for power-shovel operation in horizontal slices or benches is the most usual procedure. Most bench operations are carried on in extended straight or gently curved working faces opened at the side of the hill and advanced into the hill by successive lengthwise cuts. Some banks are opened by an initial thoroughcut normal to the contour lines which is subsequently enlarged at its inner end to form a circular or elliptical working face.

Where thin overburden (1 to 3 feet) must be removed it is often stripped by scrapers powered by gasoline tractors, mules, or horses. Such methods require the removal of the overburden in strips or areas in practically the same general scheme as is used with mechanical equipment in thicker material. Therefore, these methods will not be discussed here in detail except for the single comment that they are more expensive than where conditions warrant the use of heavier equipment.

Straight Cuts

Figure 1A represents a plan of a deposit of gravel to be worked as a bank deposit. The contours are drawn at 20-foot intervals and preliminary exploration is assumed to show an average of 5 feet of overburden which must be removed.

This deposit may be opened from either of two points. The treatment plant may be located across the creek on the flat at X with the excavation to be made lengthwise of the hill, or the plant may be at Y, with the cuts to be made transverse to the long axis of the hill. In either case the plant would be within reach of the railway. At X it would be adjacent to the highway as well, while at Y it would be necessary to build about a mile of road. At X quicker access can be had to the gravel because of the steeper hill slope.

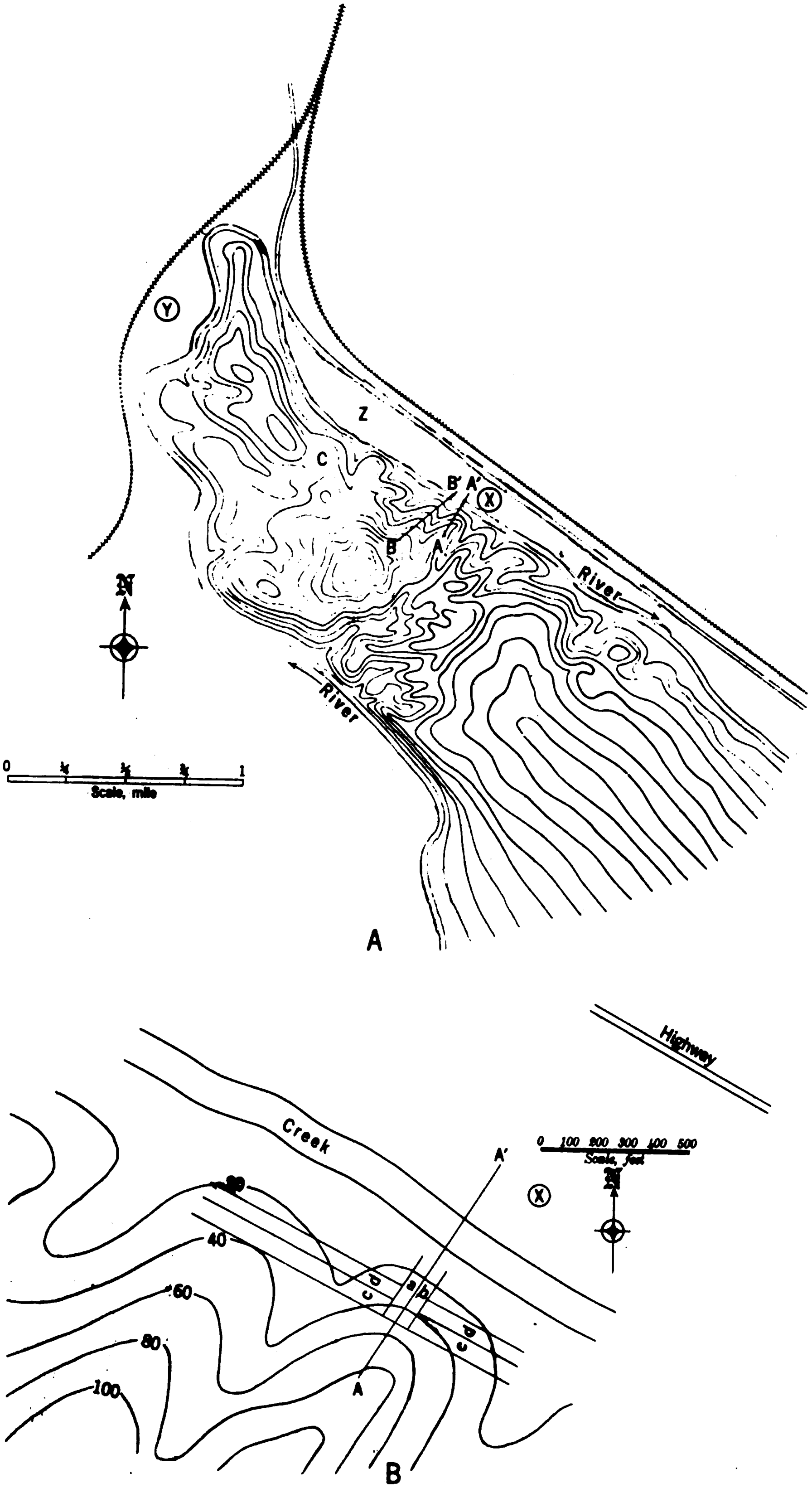


Figure 1.—A, General plan; B, detailed stripping plan

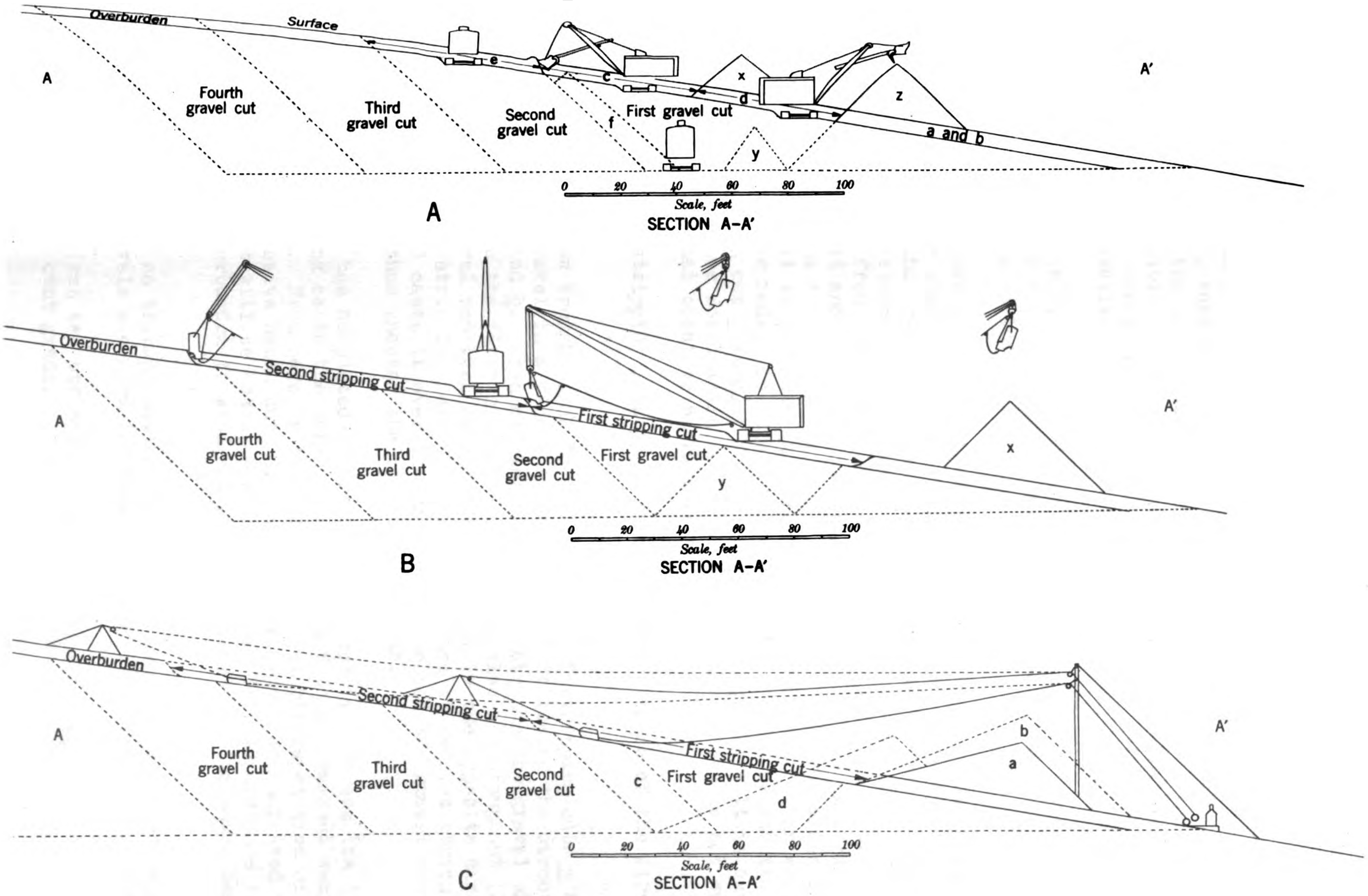


Figure 2.—A, Shovel; B, drag line; C, cableway scraper

It is assumed that the plant is at X and that there are two shovels available for stripping and gravel excavation. The shovels are equipped alike with $1\frac{1}{2}$-cubic yard dippers, each having a 24-foot dipper stick and a 32-foot boom mounted at $47\frac{1}{2}^{\circ}$ from the horizontal. It is further assumed that there is only a limited space available for waste dump along the creek and the overburden must be wasted to the excavated pit after the gravel is removed. No transportation equipment is available for moving overburden.

Figure 1B is an enlarged plan of the area at which it is decided to enter the deposit. Figure 2 shows a vertical section on a still larger scale along the line A-A' as drawn on both 1A and 1B.

The first procedure will be to take out the two stripping cuts a and b, Figure 1B. These are started about 10 feet above the elevation of the creek (it is assumed that the creek does not flood) and are advanced up the slope of the hill to such a distance as will reach the upper side of the first gravel cut. The overburden from these two cuts is cast to one side and left. Next the shovels are turned and stripping cuts c are advanced either in straight lines or following the contour of the hill, as desired. The overburden from cut c is cast downhill to x Figure 2A. Upon extension of cut c to an economical distance, cut d is made. In this cut the overburden in place and that piled on it at x from cut c is cast further downhill to z, where it is out of the way and need not be moved again, as it is assumed that there is not enough gravel below it at that point to warrant rehandling.

The removal of stripping cuts c and d exposes the surface of the first gravel cut.

One shovel is now brought back to the beginning of stripping cuts a and b and starts digging gravel in a wide entry thoroughcut following the direction of stripping cuts a and b. Upon completion of this entrance the gravel shovel is turned and removes the first gravel cut, which is also a thoroughcut (Fig. 2A). The second shovel can then extend this same cut in the opposite direction or it can be left to strip further. In the latter case it removes stripping cut e, Figure 2A, and casts it over the gravel bank behind the gravel shovel to f. This shovel can thus uncover the second gravel cut.

When the shovel has completed the first gravel cut it reverses its direction, and in returning casts the overburden piled at f to a permanent waste dump at y, Figure 2A. From here on the process is a simple repetition of this procedure, and successive bench cuts are made in the gravel as indicated by the dotted lines. It will be noted, however, that as the cuts are made into the hill the ratio of overburden to sand and gravel decreases as increased bank height is gained.

In this example no transportation equipment is required for overburden removal, and the shovels are used for both stripping and production of gravel.

In making the first two stripping cuts a and b, Figure 1B, the shovels must dig up a 20 per cent grade. If this is too great a grade for the equipment at hand to operate on properly, the point of entrance may be changed to B', Figure 1A, and the start may be made in this ridge, which will provide a 10 per cent slope by advancing the thoroughcut along the line B'-B.

As an illustration of cost calculation (but not an indication of costs) it is assumed that digging and casting overburden in the manner described will cost 8 cents per cubic yard. Disregarding the opening thoroughcut and considering only the first gravel cut, for every yard advanced in the gravel cut the following quantities of overburden will be removed in uncovering 221.4 cubic yards of gravel:

	Overburden, Cubic yards
In stripping cut *c*	31.7
In stripping cut *d*	29.4
Total overburden	61.1

The overburden from cut *c* will have been moved twice while that from *d* will have been moved only once, therefore:

	Cost
31.7 cubic yards at 16 cents =	$5.07
29.4 do do 8 cents =	2.35
Total cost	7.42

Stripping cost per cubic yard of gravel $0.034

In the second gravel cut there will be removed 35 cubic yards of overburden which will uncover 228 cubic yards of gravel. Since this overburden must also be moved twice it will cost:

	Cost
35 cubic yards at 16 cents =	$5.60

Stripping cost per cubic yard of gravel $0.024

It is obvious that if the shovels had shorter booms and dipper handles the preceding plan would have to be considerably altered. More than two cuts would have to be made in place of *c* and *d* and more than one cut would be necessary to strip the second gravel cut. Neither would it be possible to pile overburden as high as is shown at *z*, Figure 2A. There will be some contamination in casting overburden from *e* over the bank to *f*, but this can not be avoided except by providing haulage equipment.

The extra cost in handling portions of the overburden the second time is offset by the saving in haulage cost.

In case the deposit below the floor contained commercial material the method described would be less desirable because the dumped overburden would have to be rehandled. In this event it would probably be more economical to provide dumping space at the start and haul all overburden to it, even at an added cost.

As an alternative to the preceding set of conditions it is assumed that instead of having the two shovels available, the operator has one shovel and a drag-line excavator. The drag line is equipped with a 2-cubic yard bucket and a 90-foot boom hung at a 30° angle from the horizontal. The drag line will be used to do all the stripping and the shovel will be used to produce gravel.

Owing to its greater reach the drag line will be able to strip both cuts a and b, Figure 1B, in one operation and dump the overburden at x, Figure 2B. Likewise as shown in Figure 1B, the drag line can strip cuts c and d in one operation. This means handling the overburden only once. Also the overburden covering the second and third gravel cuts can be removed in one operation and dumped clear of the gravel bank, directly to the bottom of the first gravel cut as shown at y, Figure 2B. This eliminates contamination such as occurred in the former example.

For illustrating costs it is assumed that the drag line will strip and dump overburden at 8 cents per cubic yard. The first stripping cut will contain 68 cubic yards of material for each yard of advance, and will uncover 221.4 cubic yards of gravel. The cost per cubic yard of gravel will be:

$$\frac{68 \times \$0.08}{221.4} = \$0.025.$$

The second stripping cut will also contain 68 cubic yards of material, but will uncover 406 cubic yards of gravel. The cost per cubic yard of gravel will be:

$$\frac{68 \times \$0.08}{406} = \$0.013.$$

The drag-line excavator used in the example is a larger machine than the shovel and will probably cost more to install, thus raising the overhead stripping cost. However, the one machine will be able to keep two shovels in gravel production, and the reduced cost of handling the overburden will undoubtedly more than offset the added overhead. This, of course, assumes that the market will absorb the increased production from the two shovels. If not, it will probably still be cheaper to use the drag line for stripping and operate it only intermittently. Possibly the same crew can operate both drag line and shovel by doing the stripping in nonproductive seasons.

A third condition assumes that the prospective operator has no digging equipment other than the drag line itself. In this case the procedure would be the same as in the preceding example for the stripping cuts a and b except that the underlying gravel in the thoroughcut can be dug and loaded into cars as the excavation proceeds. By this method the drag line strips a short section, casting it to the bank at one side. It then digs the uncovered gravel

Original from THE OHIO STATE UNIVERSITY

to grade line. The same procedure is followed in stripping cuts c and d. The success of this method in subsequent cuts will depend upon the steepness of the gravel bank which can be maintained at the face. As the pit is advanced into the hill and the gravel gets thicker, the length of slope of the freshly cut bank will increase until finally it will become too great for the drag line to reach cars in the bottom of the cut. In this event the haulage line may be moved to the surface on unstripped ground parallel to the stripping cut. This will necessitate narrower stripping cuts so that the drag line can reach and load cars on the higher level. It will also necessitate the provision of haulage grades in lowering the gravel to the treatment plant. At this point gravel digging may be abandoned by the drag line and a shovel may be installed, thereby eliminating haulage grades and other troubles.

Figure 20 illustrates the use of a cableway scraper for stripping the ground in the example chosen for the previous discussion. The overburden from the opening thoroughcut can be removed in the initial set-up of the mast. Bearing in mind that the original assumption was that there was only a limited amount of ground available for dump and no transportation equipment was to be used, the scraper can be set up to remove the first stripping cut as shown in Figure 20. The overburden is removed by parallel cuts transverse to the advance of the gravel cut and is deposited at a. If preferred, the tailblock and tower can be set back and gravel cuts 1, 2, and 3 can all be stripped at one time in which case the material is dumped at b. This ties up considerable capital in stripping in advance of production. In case only the first gravel cut is stripped at the start the overburden from the second and third (or more) cuts can be dragged into the completed first gravel cut as at c. Before the second gravel cut is started the scraper must remove this fill c to its permanent position at d. This operation necessitates moving part of the material in the second stripping cut twice, but not necessarily all of it. A portion can be hauled to d in the first operation. Probably at least half will require moving twice, however. This method also causes contamination, and a loss of some gravel in dragging the overburden over the gravel bank (24)(58).

The illustration shows the use of a bottomless scraper with power applied in moving both the loaded and empty bucket. Similar installations are made in which the bucket is attached by chains to a trolley running on an upper or slack-line cable (38). As the bucket approaches the dump the slack line or track cable is tightened by the hoist drum, which raises the bucket to a steeper angle. It can then be returned by gravity to the digging point, the track cable loosened, and the scraper drawn to the dump again.

To illustrate cost estimates, if the first shovel cut is stripped alone, 68.3 cubic yards of overburden will be removed in uncovering 221.4 cubic yards of gravel. The cost may be estimated at $0.05 per cubic yard if a $1\frac{1}{2}$-cubic yard scraper is used which will move 380 cubic yards daily at the distance shown in the illustration. (This is one-third the manufacturer's estimated capacity.) On this assumption the cost per cubic yard of gravel is:

$$\frac{68.3 \times \$0.05}{221.4} = \$0.016$$

Assuming that the second stripping cut is moved to c and it is necessary to rehandle one-half of it to d, 73 cubic yards of overburden will be moved to uncover 406 cubic yards of gravel.

If the cost of moving one-half the dirt to c, is 5 cents per cubic yard, 4 cents per cubic yard to move it on to d, and 5½ cents per cubic yard to move one-half direct to d in one handling, we would have the following costs:

Overburden, cubic yards	Cost
36.5 at $0.05	$1.83
36.5 at .04	1.46
36.5 at .055	1.91
Total	5.20

$$\frac{\$5.20}{73} = \$0.071 \text{ per cubic yard of overburden.}$$

$$\frac{\$5.20}{406} = \$0.013 \text{ per cubic yard of gravel.}$$

If gravel cuts 1, 2, and 3 are stripped at one time, and the overburden is moved to b, the cost may be estimated as follows:

The removal of 141.3 cubic yards of overburden to b will cost 6.4 cents per cubic yard, and will uncover 627.4 cubic yards of gravel. The cost per cubic yard of gravel will then be $0.014.

The manufacturer's estimate of capacity for the drag scraper has been reduced by two-thirds in computing costs because of the necessity for frequent moving of the head mast and tail pulleys on account of the shallow digging.

In this last example it has been assumed that the gravel will be dug by shovels after the scraper has stripped it. The drag scraper might also be used to dig the gravel, but in such case better operating conditions would be provided by altering the development plan to fit the scraper operation. In other words, a development plan would be used which did not necessitate long cuts parallel with the contours or long axis of the hill, as was assumed at the start of this discussion of bank deposits.

Numerous other combinations of equipment might be suggested and doubtless could be applied with equal or better efficiency under different local conditions or individual preferences, but the examples discussed will serve to illustrate several methods of development and their advantages and disadvantages.

The costs used in these calculations are to be considered indicative only, and while they are based on actual operations they are subject to fluctuation with local physical conditions, wage scales, etc. Also while the costs estimated for one type of equipment are lower than for another, it is not intended to infer that that type of equipment is the cheapest to operate.

Original from THE OHIO STATE UNIVERSITY

If the assumptions upon which the preceding discussions are based are changed to concede ample waste space for a permanent dump and transportation equipment there will be little change in the general mode of development. For shovel and drag-line stripping the entrance thoroughcut may be eliminated. Stripping will then start on the floor of the pit and proceed parallel to the axis of the hill or to the contour lines. The overburden will be hauled away as it is dug. The initial gravel cut will then become a bench cut instead of a thoroughcut. The drag scraper, however, will require the use of some form of portable hopper to which the material will be dragged and from which it may be loaded to transfer equipment.

The cost of loading overburden to transportation equipment by shovel and drag line will be somewhat higher than for simple casting. This increase in cost is due to the necessity for more careful manipulation to spot the dipper or bucket over cars or trucks while dumping. Delays due to the absence of a continuous string of empty cars increase digging costs. There will also be the added transportation cost, the amount of which will depend upon the length of haul, condition of haulage ways, and type of equipment used. In some localities there will be an additional cost for maintaining the dump.

Simple casting in one or two stages will usually provide the most economical method of stripping when conditions are such as to allow the use of this method.

In the examples discussed, the ratio of overburden to gravel was low. If a higher ratio is assumed - as for instance 20 feet of overburden - the whole plan of development will have to be changed. For illustration, in Figure 2A the shovel, excavating stripping cut d, has about reached its limit in dumping height in the pile z. If 20 feet of overburden had to be removed this shovel could not cast it to z. The drag line in Figure 2B, however, because of its greater reach would have less difficulty in casting the overburden clear of the workings, but narrower stripping and gravel cuts would be necessary. The cableway scraper also could be operated so as to drag the greater depth of overburden to a permanent dump. The cost of stripping per ton of gravel would be greatly increased. The initial thoroughcut in gravel would have to start at about the third gravel cut in Figure 2A because cuts 1 and 2 would contain too high a ratio of overburden to pay to strip.

Circular or Elliptical Cuts

Although a short entering thoroughcut and an initial opening thoroughcut were used to open the deposit in the preceding examples, the development was arranged for straight bench operation parallel to the long axis or contours of the hill. Opening by thoroughcut normal to the hill slope involves driving the initial cut directly into or through the deposit and enlarging the opening within the deposit to a circular or elliptical working face. To some operators this form of development affords an advantage over long straight cuts in permitting a circular loading track in which no switches are required (51). Loaded and empty trains travel in a single direction around the loop. As the working face is extended and the diameter of the circle grows, much of this advantage is lost in the constantly lengthening haul. Where more than one

Original from THE OHIO STATE UNIVERSITY

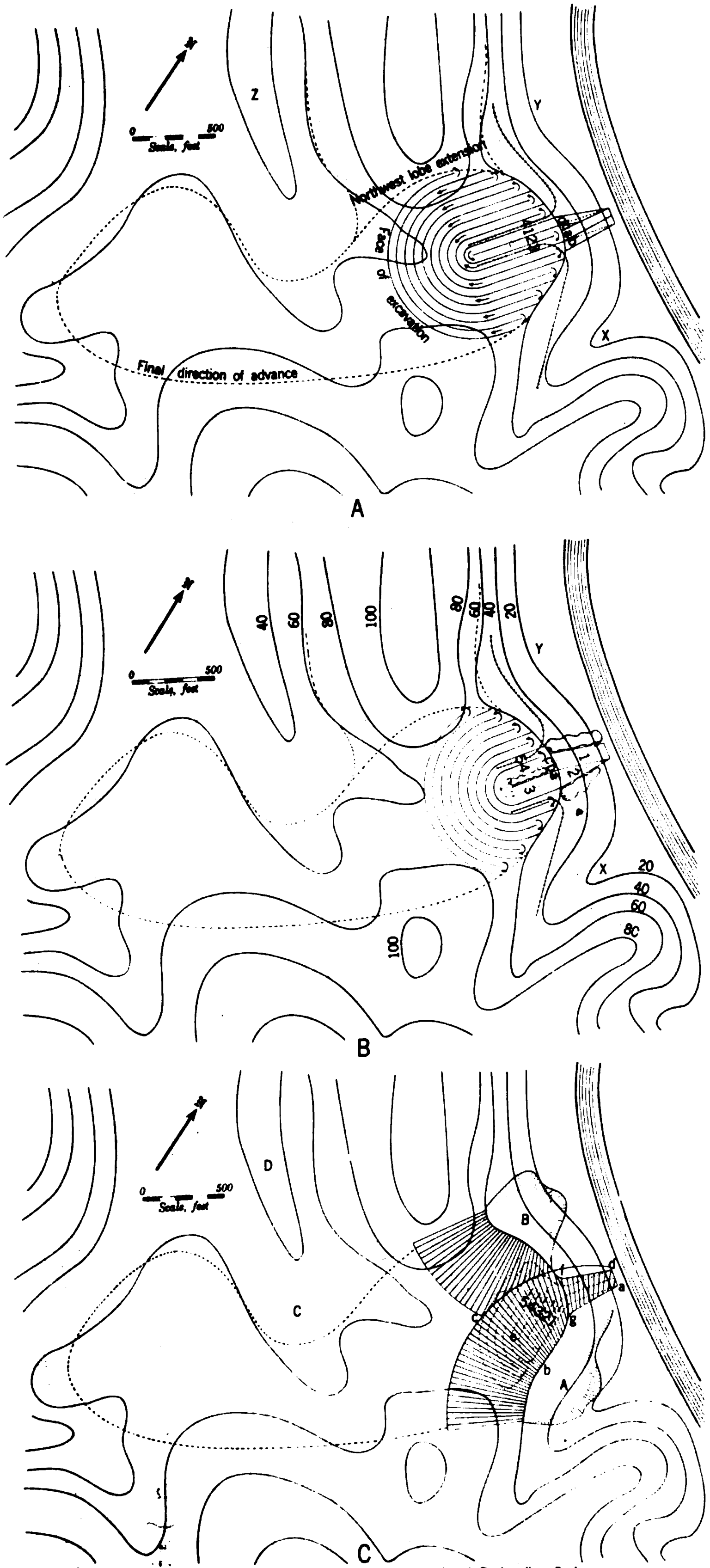


Figure 3.—Bank development by thoroughcut entry: A, using shovel; B, drag line; C, drag scraper

shovel is used for production it may become necessary to provide loading switches at each shovel so that empty trains can pass to the shovel beyond.

Opening an elliptical face by thoroughcut has the disadvantage of requiring considerable stripping ahead of production. Until the pit has been enlarged sufficiently to provide dumping space, the overburden must be removed to a temporary dump or else a permanent dumping area must be provided.

Drag-line excavators equipped with long booms can cast overburden to the excavated pit if the bench height is not too great (13).

Auxiliary equipment may be had in the form of a portable hopper to which is attached a long cantilever boom carrying a conveyor belt. With this unit the stripping shovel may load to the hopper, which casts the dirt to the excavated pit beyond the gravel digger (25).

Circular bank operations lend themselves better than straight bench cuts to development by cableway scrapers.

Referring to Figure 1A, the deposit may be opened by an entering thoroughcut at c and the plant may be located at z. Figure 3A shows a detailed plan of this area as designed for shovel stripping.

For purposes of illustration, it is assumed that the same equipment is available as in the previously discussed examples but that in the area shown in Figure 3A there is an average of 10 feet of useless overburden. The heavy dotted lines show the proposed opening of the deposit in an elliptical form with eventual extension of the excavation in a southeasterly direction by successive curved cuts transverse to the long axis of the hill. A northern extension can be made by running a lobe into the low hill in that direction. It is further assumed that both locomotive and cars, and auto trucks are available for hauling overburden to temporary or permanent dumps.

Under the first condition in which the operator has two 1½-cubic yard shovels available, the stripping may be started for the entering thoroughcut by removing cuts a, b, c, and d shown in full lines, Figure 3A. These shovels will strip an area in which a thoroughcut 100 feet wide at grade (shown by dotted lines) may be driven. While various schemes may be employed the following is used as an illustration of procedure. Shovel 1 is started 10 feet above the creek level in cut a. When it has proceeded a sufficient distance, shovel 2 is started on cut b. When shovel 1 has completed cut a to the 60-foot contour or crest of the hill, it may continue and strip the top of the hill or it may be brought back and started on cut d. In the latter case shovel 2 upon completing cut b would move over and take out cut c ahead of shovel 1. Upon completing cut c it may be returned to the base of the hill and start producing gravel in the entering thoroughcut. Shovel 1 upon completing cut d will then proceed with the stripping on top of the hill.

Since these stripping cuts must be driven up a grade of approximately 15 per cent it will be difficult to maintain a haulage track parallel to the shovel advance on which cars may be spotted. Therefore it is assumed that the operator will use trucks to haul this overburden to the dumps. Material from cuts a and b will be hauled approximately 500 feet to a temporary dump at X while that from c and d will be hauled to Y. The trucks will operate on the original ground.

This opening thoroughcut to the 60-foot contour will involve the removal of roughly 17,700 cubic yards of overburden, uncovering 25,000 cubic yards of gravel. Stripping cuts a and b will contain 6,200 and 5,200 cubic yards of overburden, respectively, while c and d will contain 2,100 and 4,200 cubic yards. Material from a and b will be hauled 500 feet, while that from c and d will be hauled about 700 feet. This difference in hauling distance will make little additional cost because of the temporary nature of both dumps. It may, however, require one more truck to serve the shovel and keep it busy.

Assuming a cost of 8 cents per cubic yard for digging, 5 cents for hauling to X, and 6 cents for hauling to Y, the cost of stripping the entry thoroughcut would be:

			Cost
Cut a,	6,200 cubic yards at	13 cents	$806.00
Cut b,	5,200 do	13 do	676.00
Cut c,	2,100 do	14 do	294.00
Cut d,	4,200 do	14 do	588.00
	Total cost		2,364.00

This represents a stripping cost of 13.4 cents per cubic yard of overburden or 9.5 cents per cubic yard of gravel uncovered.

Shovel 1, having completed cut d, will proceed to remove No. 1 stripping cut as shown in Figure 3A. This cut may be driven for whatever distance is deemed economical. In the example it is taken as 550 feet, at which point the direction of the shovel is reversed and it returns on cut 2. Haulage tracks to dumps X and Y from cuts 1 and 2 are shown. These may be connected aound the ends of the stripping cuts and the material moved to either dump at will. Trucks may be used in lieu of locomotives and cars on this haul. After completing cut 2, the direction of the shovel is again reversed, and it starts work on cut 3. In cuts 1 and 2 shovel 1 has removed roughly 23,000 cubic yards of overburden. During this period shovel 2 should have about completed the entry thoroughcut in the gravel. As shovel 1 now advances on No. 3 stripping cut, shovel 2 follows in gravel under what was stripping cut 2. In this manner one shovel strips ahead of the other, making cuts as indicated by the arrows. The gravel shovel removes gravel cuts located the same as the stripping cuts but starts on cut 2 and reverses direction returning under cut 1.

By this method a minimum of thoroughcutting is necessary and advance stripping is confined to cuts 1 and 2. The excavation face is carried in elliptical form and an endless haulage system may be maintained at all times. No overburden is returned to the excavated pit, and permanent dumps must be maintained because the stripping shovel has not sufficient reach to dump into the pit beyond the gravel track. As the face advances beyond the stripping cuts shown in the drawing a permanent dump will be established at Z and those at X and Y will be abandoned.

The hauling distance for material from stripping cuts 1, 2, and 3 will be roughly 300 feet. Because of the more permanent character and lower grades of the haulage way, a transportation cost of 5 cents per cubic yard is assumed in spite of the increased distance. It is also assumed that the shovel digging cost will have decreased to 7 cents per cubic yard on the top of the hill. An estimate of development cost will then be as follows:

				Cost
Stripping cut	1,	13,100	cubic yards at 12 cents	$1,572.00
Do	2,	11,100	do	1,332.00
Do	3,	12,500	do	1,500.00
Do	4,	12,500	do	1,500.00
			Total	5,904.00

These four cuts will uncover gravel cuts 1 and 2 which contain roughly 80,000 and 47,000 or a total of 127,000 cubic yards. The stripping cost is then $0.047 per cubic yard of gravel uncovered. Stripping cut 4 was included in the above calculations because a circular haulage track can not be installed until gravel cut 2 has been removed. This necessitates the completion of stripping cut 4.

Completion of gravel cut 2 and stripping cut 4 finishes what may be termed the "pit development," and the cost may be summarized as follows:

	Cost
Stripping entry thoroughcut	$2,364.00
Thoroughcut in gravel, 25,000 cubic yards at 21 cents	5,250.00
Stripping cuts 1, 2, 3, and 4	5,904.00
Gravel cuts 1 and 2, 127,000 cubic yards at 21 cents	26,670.00
Total	40,188.00

The assumed cost of removing 66,900 cubic yards of overburden amounted to $8,268.00, or an average of 12.3 cents per cubic yard.

A total of 152,000 cubic yards (228,000 tons at 3,000 pounds per cubic yard) of gravel was removed in development. The stripping cost was 5.4 cents per cubic yard of gravel or 3.6 cents per ton. Assuming an excavation cost for the gravel of 21 cents per cubic yard (digging and hauling) or 14 cents per ton, the cost of development was 17.6 cents per ton of material recovered.

Since the removal of 1 cubic yard of overburden in subsequent operations will uncover 4 cubic yards or 6 tons of gravel the operating cost for stripping will be $\frac{\$0.123}{4} = \$0.031$ per cubic yard, or $0.0205 per ton of gravel.

In the second example, in which the operator has one drag line and one shovel available, the development scheme may be carried on along a similar general plan, although the details will be quite different. Figure 3B shows a plan of development for this combination of equipment.

The drag line is started in stripping cut 1, which because of the greater reach of the drag line may be 100 feet wide. The machine can also cast the overburden to the side of the cut and thus avoid the expense of hauling it to temporary dumps. Having completed stripping cut 1 to the 60-foot contour the machine is returned and started on cut 2, the material from which it also casts to the side, as shown. With cuts 1 and 2 stripped the shovel can start producing gravel from the entering thoroughcut, 100 feet wide on grade, as shown by the dotted lines.

The drag line then continues work on stripping cut 3 which is also 100 feet wide. Material from this cut must be hauled to temporary dumps either by locomotives and cars over tracks as shown, or by trucks. Proceeding an economical distance (300 feet in the illustration) the drag line returns on cut 4, also 100 feet wide, the overburden from which is hauled to temporary dumps. This leaves an area 200 by 300 feet in size ready for excavation. The gravel shovel now enters the deposit by thoroughcut a and returns by bench cut b.

The drag line has started back on stripping cut 5, which is only 50 feet wide. A part of the material at the start of this cut will have to be hauled to dumps, but when the shovel has completed cut b and starts back on cut c the drag line can cast material from cut 5 to the excavated gravel cut b, thus avoiding a haul to permanent dumps. Thereafter the drag line precedes the shovel and casts the overburden to the cut just completed by the shovel.

In stripping cuts 1 and 2 the boom of the drag line will have to be elevated to 40° from the horizontal to obtain sufficient height to dump to the waste piles. In cuts 3 and 4 the same angle may be used, but in cut 5 the boom must be lowered to 30°, or lengthened, to provide sufficient reach to dump material beyond the gravel tracks.

Stripping cuts 3 and 4 may be extended considerably beyond the distance shown in the illustration. They have been stopped at 300 feet in the example to provide a minimum area from which the overburden must be hauled to dumps. It is obvious that in rounding the inner end of stripping cut 5 the excavated area in gravel cuts a and b will not provide sufficient space for the overburden. Part of this material will have to be hauled to dumps. As the excavation increases in area, however, this difficulty will be overcome and all the overburden may be cast to the excavated area.

Assuming that the overburden from cuts 1 and 2 will be cast to the side, and that from 3 and 4 will be hauled to the dumps X and Y, the following illustration of development cost may be computed. It is considered that development ends with completion of gravel cut b and before starting stripping cut 5. Drag-line excavation is assumed to cost 8 cents per cubic yard in cuts 1 and 2 and 7 cents in cuts 3 and 4, and shovel excavation to cost 21 cents per cubic yard in gravel. Haulage of overburden to dumps X and Y is assumed to cost 5 cents per cubic yard.

				Cost
Stripping cuts 1 and 2, 17,700	cubic yards at	8	cents ...	$1,416.00
Stripping cuts 3 and 4, 30,500	do	12	do ...	3,660.00
Gravel entry thoroughcut, 25,000	do	21	do ...	5,250.00
Gravel cuts *a* and *b*, 74,000	do	21	do ...	15,540.00
Total development cost				25,866.00

The average cost of stripping is 10½ cents per cubic yard of overburden or 3.4 cents per ton of sand and gravel recovered. The total cost of development is 17.4 cents per ton of material recovered from the development.

Since the removal of 1 cubic yard of overburden in subsequent operations will uncover 4 cubic yards or 6 tons of gravel and the overburden will be cast to the excavated pit without hauling, the operating cost for stripping will be $\frac{\$0.08}{4} = \$0.02$ per cubic yard or $0.013 per ton of gravel.

Figure 3C illustrates a method of development by the use of the drag scraper and shovel, as in the third assumed set of equipment.

The drag scraper is set up first to remove the overburden from the entry thoroughcut and the eastern portion of the deposit to a permanent dump at A. The scraper is then set up to remove the overburden from the northern portion of the deposit and to dump it at B. Having completed this stripping the scraper is next moved to C, where as much dirt is dumped as the space and elevation will allow. Then a second scraper is set up to relay the material from C and haul it to the permanent dump at D. These two scrapers will work together, and by their use all but the extreme western portion of the proposed pit can be stripped.

This arrangement is designed to provide the simplest manipulation of equipment for stripping without regard to the extra investment involved in extensive stripping ahead of production. The overburden is removed in radial cuts in circular segments as shown. This involves roughly the movement of 177,000 cubic yards of overburden an average distance of 500 feet to dump A and 112,000 cubic yards a similar distance to B. The removal of this overburden would uncover roughly 1,113,000 cubic yards or 1,670,000 tons of sand and gravel.

Taking 75 per cent of the manufacturers estimate of capacity at this hauling distance for a 3-cubic yard scraper, the cost of stripping may be estimated at 9 cents per cubic yard of overburden, or 1½ cents per ton of sand and gravel.

With 390 cubic yards as the average daily capacity of the scraper and 500 cubic yards as that of the 1½-yard shovel, the overburden would be removed from the two segments in 741 days, but it would require 2,265 days to remove the gravel. Obviously this arrangement would tie up considerable money in stripping which would have to be carried as a deferred charge.

The scheme just discussed involved stripping the entry thoroughcut with the scraper. This work may be done by the shovel as in Figure 3A and the scraper started at the 60-foot contour. A further change may be made by confining the first stripping going to dump A to that area overlying gravel cuts 1, 2, and 3 as shown on Figure 3C. Gravel cuts 4, 5, etc., may then be partially stripped to dump B. Referring to Figure 3C, the area a, d, f, g, (the entry thoroughcut) will be stripped by the shovel. Area g, f, e, b will be s stripped to dump A and area e, f, c to dump B.

Rough calculations indicate the following quantities and costs.

	Cost
Entry thoroughcut, 17,700 cubic yards overburden at 13.4 cents ...	$2,364.00
Area g, f, c, b, 35,400 do do at 7.5 do ...	2,655.00
Total development stripping	5,019.00

Scraper stripping is estimated at 7.5 cents because the average haul in this case would be only 400 feet.

The removal of this overburden would uncover the entry thoroughcut and also gravel cuts 1, 2, and 3. Cuts 1 and 2 could now be made without further stripping, but cut 4 would have to be stripped before the removal of cut 3 because of the slope. Stripping of cuts 1 and 2 and their removal will complete development and permit the installation of an elliptical haulage system. Subsequently stripping may be continued with production.

Development stripping will permit removal of roughly 25,000 cubic yards of gravel from the entry thoroughcut and 80,000 yards from cuts 1 and 2. Therefore the stripping will cost 9.5 cents per cubic yard of overburden or 3.2 cents per ton of gravel recovered.

On a time basis the shovel will strip the entry thoroughcut in 35 days and remove the gravel from it in 50 days. It will require 100 days to remove cut 1, or a total of 185 days for the shovel to advance to the inner end of cut 1.

The scraper will have removed the overburden from cuts 1, 2, and 3 in 75 days so that it will be well ahead of the shovel and will have started stripping cut 4 before the shovel reaches cut 3.

It will be noted that the gravel cuts have been driven parallel to the 60-foot contour and not directly into the deposit. In doing this the pit face is advanced from one side only of the opening thoroughcut 1, but a permanent haulage way may be maintained in cut 1 for empty trains entering the pit.

Elevated Bank Deposits

Those deposits of sand and gravel which are located on the tops of mountains or eroded plains occupying a position of considerable elevation above the general land surface do not present problems in development greatly different from those of deposits composing the whole hill. The preparation of the deposit for exploitation will follow the same rules in both cases except for the method of transferring the recovered material to the treatment plant on the lower level. This must be considered in laying out the development scheme, but since it affects the preparation of the deposit itself only in a minor way and the problem is in reality one of interplant transportation, a discussion of this phase falls more logically under the head of excavation and haulage. For this reason discussion of this type of bank deposit will be left for future publication under the proper heading.

Thick Bank Operations

There are some deposits which present problems peculiar to their extreme vertical thickness. These are exemplified by the great alluvial cones of the West and the beach deposits of Great Salt Lake. Attaining a thickness at times of several hundred feet, the operation of such a bank by single-bench methods would present a safety problem of no mean proportions. The natural slope of these cones has been eroded to an angle with the horizontal less than that at which the material will move by gravity. Undercutting by shovel at the toe of the slope is apt to loosen the material so that dangerous slides of the upper bank occur. These slides have been known to bury the entire shovel and haulage equipment at times and to cause loss of life. This difficulty has been overcome at some plants by the use of hydraulic jets to cave the bank ahead of the shovel (34)(50)(67). In some instances this type of deposit can be worked in multiple benches, starting at the top. Development of the highest bench then becomes a problem similar to those described for ordinary banks except that provision must be made for lowering material by curved descending haulage ways, switch backs, or inclined gravity planes. Development by such means will be discussed under the heading of excavation in a later circular.

In some instances, however, this type of deposit may be worked in the form of an inclined trough or inverted cone (27)(32)(53)(63). This method of operation lends itself readily to the use of drag scrapers. Ordinarily such deposits present such a low ratio between overburden and gravel that the former may be disregarded entirely. The overburden is allowed to cave onto the gravel and is excavated along with it. In case the ratio is considered too high for elimination of the overburden in the washing plant the scrapers may be set up to remove the overburden directly to permanent dumps or to movable hoppers from which it may be hauled to dumps. Figure 4 illustrates a thick deposit operated as an inverted cone by drag-scraper methods. The gravel is assumed to be 300 feet thick above the plain at the base and to be covered with 5 feet of overburden. Normally this would be an exceedingly thick mantle for this type of deposit. The area shown in plan contains roughly 8,000,000 cubic yards of recoverable material of which less than 200,000 is overburden, or a ratio of 1 overburden to 40 gravel. Ordinarily under these conditions the overburden would be disregarded and excavated along with the gravel and there would be no so-called development. The drag scraper would be set up at C at the base of the hill with the tail pulley at the top of the slope, and excavation would begin. The initial excavation, however, would obviously have a much increased overburden ratio. This might be so great that the material from the first shallow cut would have to be hauled to a waste dump. Subsequent cuts, however, would cave the overburden gradually so that it would be thoroughly mixed with the gravel.

If it were necessary to strip the slope of the hill this could be done by setting the scraper mast to the right (fig. 4, Y) or left (fig. 4, X) of the gravel digging position and scraping the overburden to waste piles on the plain. The top of the hill would have to be scraped back from the slope.

The illustration shows progressive excavation cuts with the first position of the tail pulley at A on the top of the slope. It is then gradually moved back to B, then radially to C and D, and so on to the limit of hauling distance (in this case chosen at 1,000 feet.)

Hydraulic Development

At a few deposits the overburden is removed by hydraulic stripping, and in one or two instances the underlying gravel has been hydraulicked to a central sump, from which it was lifted by pump to the treatment plant.

Hydraulic operations are limited to those few deposits having the peculiar physical characteristics suitable for that type of operation (60). A first consideration is the presence of sufficient water supply. This should preferably be located above the deposit in order that it may be moved to the point of use by gravity at sufficient pressure to be effective. Hydraulicking with water pumped from a lower source, although practiced in some instances, loses much of its advantage due to the cost of pumping. A second consideration is the surface slope of the deposit, which should be toward a deep ravine or drainage basin of sufficient size to accommodate the material washed to it. Because of local regulations it is not always possible to wash overburden into streams, so that the dump must be impounded in settling basins behind dams.

There are other conditions necessary where the deposit itself is to be hydraulicked, but these relate to excavation and will be discussed under production methods. One requirement, however, must be considered for hydraulic development: Transportation of gravel in flumes or sluices from the working face to collection sumps requires operating grades of from 5 to 10 per cent, depending upon the coarseness of the material transported and the type of sluice used. This means that as the working face proceeds away from the plant its lower limit rises rapidly. Thus a sluice requiring a 10 per cent grade will render 10 feet of gravel unavailable in each 100-foot advance of the face. It is obvious that a deposit must be of more than ordinary thickness or be deposited upon an inclined stratum to be extensively worked by this method (60). Collection sumps at grade level may be made at intervals as the face advances, and the sluices should be kept short. This will overcome the grade difficulty, but it means pumping rather than sluicing the gravel an increasing distance to the plant, and consequent added expense. Development for hydraulic operation must take this item into account, although if the overburden only is to be removed by hydraulic methods it becomes of minor importance.

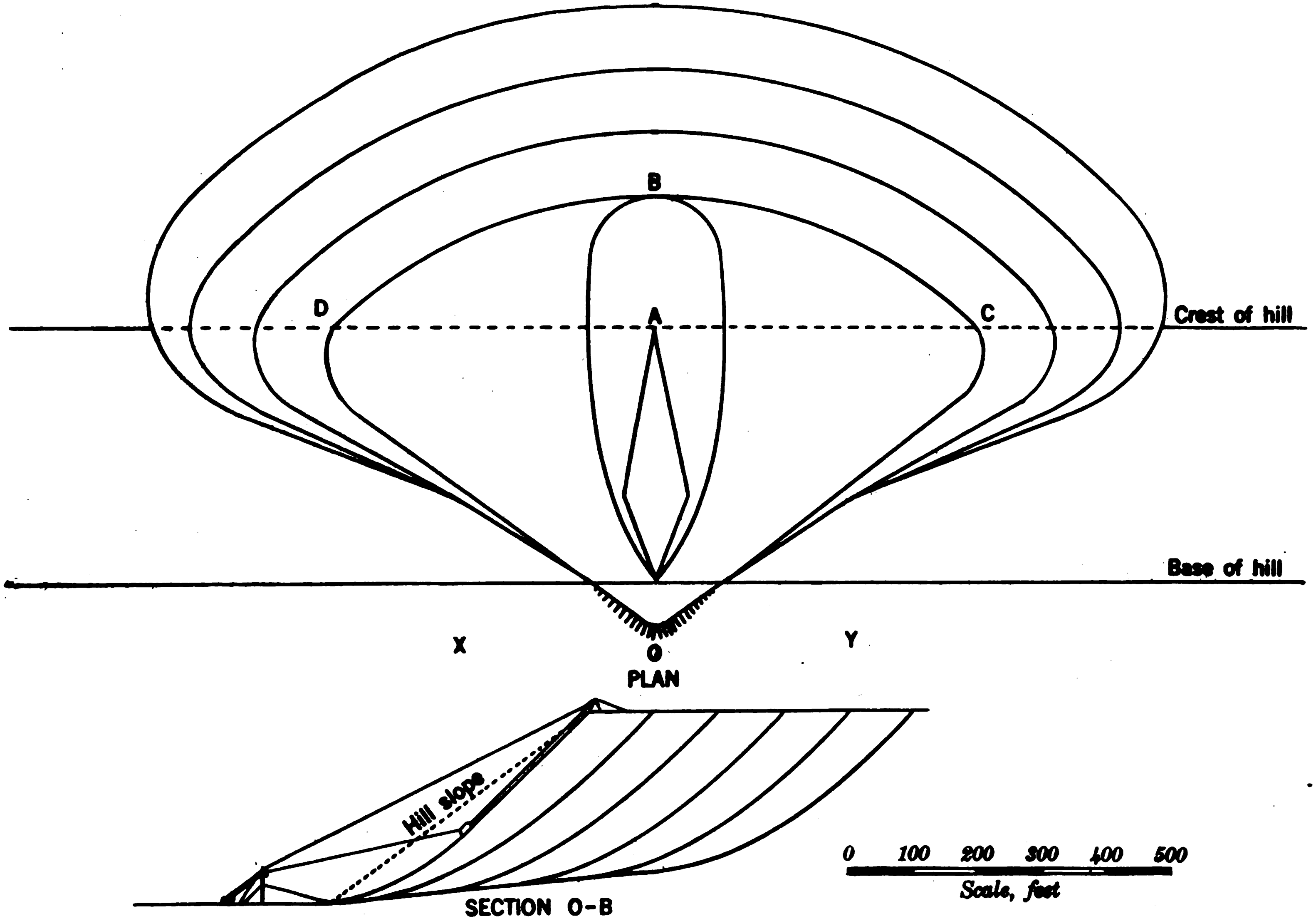


Figure 4.—Plan and section of drag-scraper trough

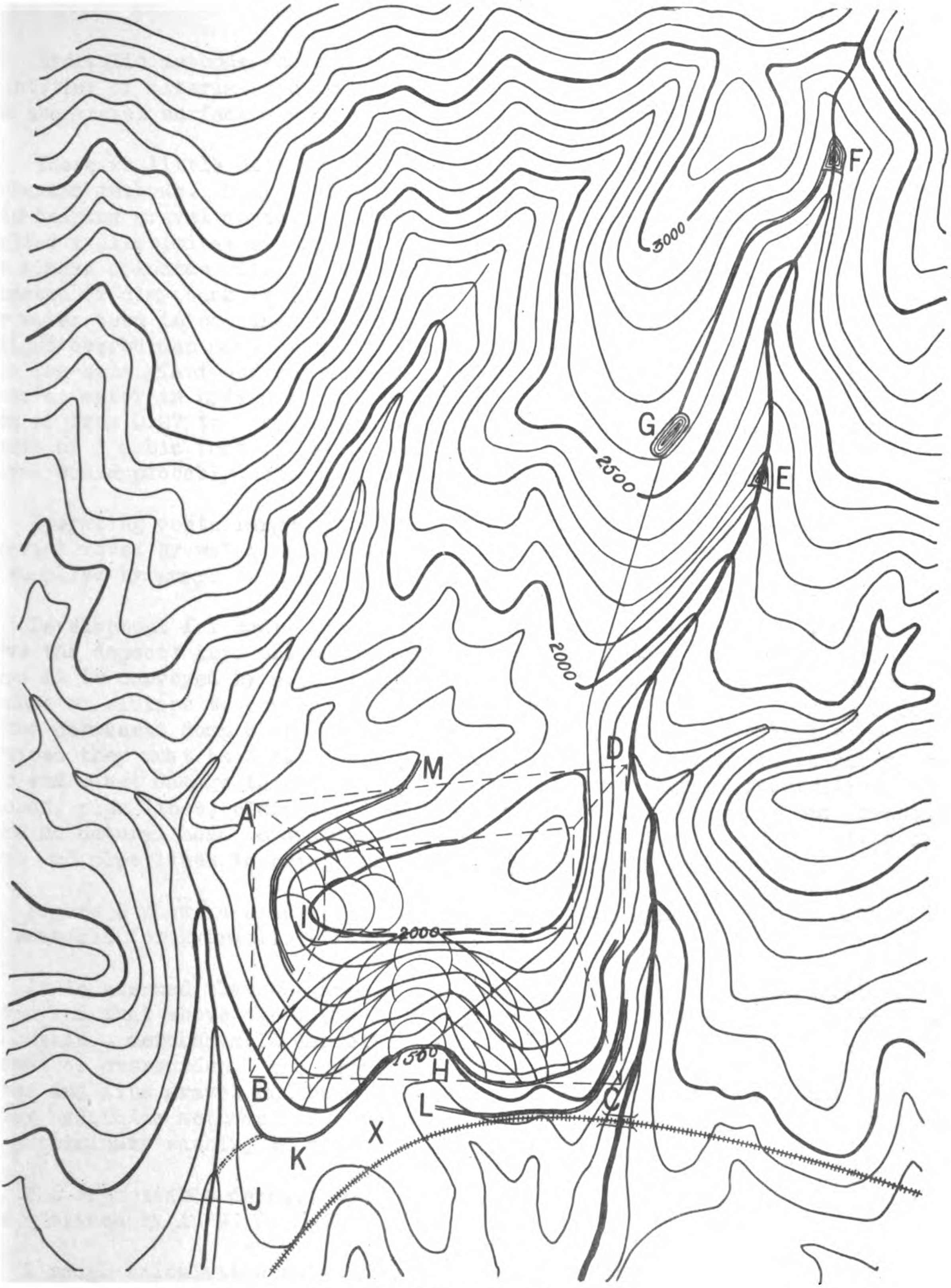


Figure 5.– Plan of hydraulic operation

Hydraulic methods where conditions permit are cheap and efficient. Large quantities of material can be moved with a minimum of labor and equipment, and the gravel surface may be washed clean of all deleterious material.

There is little data available regarding the movement of overburden by hydraulic methods. Many tables have been published showing the quantity of gold-bearing gravel moved per miner's inch of water used but these can not be applied indiscriminately because the cutting power of hydraulic giants does not always coincide with the transporting power of the water used. A heavily cemented or clay bank may cut so slowly as to produce much less material than the water used in cutting may be capable of transporting. On the other hand a light overburden may cut and wash away much faster than would be the case were the same giant and water used in gravel. As an indication of the digging power of water in hydraulic gold-mining operations, records show that excavation of from 0.27 to 7 cubic yards of gravel per 24 hours is possible with a volume of 1 cubic foot of water per minute. Stripping light overburden from gravel would probably conform to the higher figures in this range.

Operating costs range all the way from 2½ to 25 cents per cubic yard for material moved by water under natural head and up to 60 cents where the water is supplied by pumps from a lower level.

Development for hydraulic stripping includes the location of reservoirs above the deposit into which the water is led by ditches or streams. From these it is conveyed by pipe line to the deposit. Provision must be made for ditches or sluices to convey the water and overburden from the working face to the permanent dump or ravine or behind retaining dams. If the latter are required they must be located where they will be of most benefit to the operator and least damage to others. All this entails designing reservoirs, ditches, pipe lines, sluices and disposal sites to the best economic advantage. Where no natural head is available, development requires the installation of pumps and pipe lines to bring the water from available sources.

Figure 5 shows a plan covering an alluvial fan area in which conditions are suitable for hydraulic stripping.

It is assumed that the area under consideration has been thoroughly prospected and that above the 1,500-foot elevation the alluvial fan has been found to contain a merchantable deposit of sand and gravel covered by an average of 10 feet of overburden. The deposit itself consists of a typical mixture of coarse and fine gravel and sand with some clay lenses. It is decided to employ hydraulic methods for both stripping and excavation in order to utilize the preliminary washing in removing the clay.

The exploitable deposit conforms roughly to a truncated pyramid with a base outlined by A, B, C, D, Figure 5.

A rough calculation shows the presence of 80,000,000 cubic yards of material of which the overburden, averaging 10 feet deep, composes about 3,000,000 cubic yards, leaving 115,500,000 tons of marketable material, inclusive of the clay, within the deposit. A production of 5,000 tons daily could be maintained for over 60 years.

Original from THE OHIO STATE UNIVERSITY

Assuming that a flow of 1 cubic foot of water per minute applied hydraulically will remove and sluice 3 cubic yards of overburden or 2 cubic yards of gravel in 24 hours, the removal of 1,000 cubic yards of overburden daily will require a flow of 350 cubic feet or 2,625 gallons per minute.

If the point X, Figure 5, is selected as a suitable location for the screening plant the slope of the gravel hill immediately adjacent (base B, C) will contain roughly 1½ million cubic yards of overburden. Removing this at the rate of 1,000 cubic yards daily would require over three years; therefore it is assumed that double this quantity of water will be necessary for stripping, or 700 cubic feet per minute. A hydraulic giant with a 3-inch nozzle operating under an effective head of 300 feet will throw approximately 350 cubic feet of water per minute; therefore 700 cubic feet of water per minute will operate 2 giants and permit the removal of 2,000 cubic yards of overburden per 24 hours. Upon stripping sufficient area only one giant need be kept at the stripping, while the other may be used to mine the gravel.

Since production is required at the rate of 5,000 tons or 3,333 cubic yards daily, at least 1,700 cubic feet of water per minute will be needed for gravel production, which with, say, 350 cubic feet on subsequent stripping will total 2,050 cubic feet or 15,375 gallons of water per minute.

This then may be taken as the assumed water requirement. The first step in the development program is to locate the water supply and to determine the method of transportation and location of pipe lines or ditches.

Preliminary prospecting it is assumed has shown that the main stream through the property has a flow of 25,000 gallons per minute during dry seasons; therefore ample water supply is assured.

Since there is a difference of 500 feet in elevation between the bottom and top of the gravel deposit, the location of a water source at the proper head for hydraulic operations at the base of the hill will not give sufficient head at the top. If the source is located for sufficient head at the top of the deposit the pressure at the base will require some pressure-reducing device. Therefore two sources of water supply have been selected, one at E for the lower operations and one at F for the upper workings. Each will supply water at 600 feet of head, which is more than is needed for hydraulic operation—400 feet of head being the ordinary maximum pressure used.

The water from F may be carried by open ditch to a reservoir at G and there turned into the pipe line. In order to provide proper facilities for removing the water from the creek, small dams will be required at E and F and a reservoir at G. From E a pipe line will convey the water to the base of the hill at H where stripping will begin. From G the water will be conveyed by pipe line to I at the top of the hill for stripping operations there.

The next problem confronting the operator is the disposal of waste overburden. It is assumed that local regulations forbid dumping this material to running streams. It must then be confined behind dams in settling basins.

This can be done by constructing an earth dam in the second creek at J. The construction of the dam itself can be accomplished by manipulation of the stripping sluices. As the basin fills up, more material can be built up on the dam.

In order to carry the overburden to the dump site at J, the ditch K will be necessary. This ditch as shown is cut on a grade of 5 per cent which is considered ample to carry the overburden. It will be noted that the upper end of the ditch is considerably above the 1,500-foot contour or base of gravel operations. Material lying below this ditch and above the 1,500-foot contour can be washed to the hollow at L through a second ditch, as shown. For stripping the top of the deposit a third ditch is constructed to deliver waste to a dump in the valley at M.

This completes the major operations and stripping is started at H. The giants wash the overburden down the hill to the ditch K in which it is carried to the dump. The giants may be moved up the slope of the hill as shown by the circles, and stripping may be extended laterally as shown by the curves. One disadvantage with this method is that the moving overburden and water pass continually over gravel that has been stripped at a lower level on the hill. As a variation, after the first stripping has reached the top of the hill the giants may be so directed as to cut parallel strips down the slope of the hill and thus leave the previously stripped area dry. To do this, owing to the local contours, would necessitate a triangular-shaped stripping area with the base of the triangle at the upper elevation. Considerable stripping ahead of excavation would then be required because the latter would start at the base of the hill.

In case the overburden was thin and not heavy clay it is extremely doubtful if stripping would be necessary in this example. The ratio of overburden to gravel is low and hydraulic mining will prewash the material rather thoroughly. In such case production would start at H by hydraulicking to a sump from which the material would be pumped to the treatment plant.

In computing the cost of development in the example cited, such items as the construction of dams on the creek, reservoir at G, ditches, and dumps at J, L, and M must be included, together with a proportion of the cost of laying pipe lines. The cost of stripping such area as was necessary before excavation of gravel must also be included. Since the example cited is purely theoretical and the cost of the items mentioned will vary greatly under specific local conditions, development costs are not computed for this example.

PIT DEPOSITS

Deposits of sand and gravel which are operated as dry or wet pits may be of any geologic origin. The method of operation is governed more by the location of property lines with respect to topography than by the genesis of deposition. As may be expected they also present a variety of conditions with respect to thickness and character of both overburden and contained material. Another condition to be considered, absent in bank operations, is the presence

Original from THE OHIO STATE UNIVERSITY

of permanent ground water and its position with reference to the gravel bed. This will in most cases determine whether the deposit shall be operated as a dry or wet pit. Although it may be possible to work the upper portion of some deposits dry it may be found more economical to work them wet as a whole. In such cases that part of the deposit above ground water is caved and extracted from below the water surface (44).

The selection of operating equipment will also be governed by the position of the ground-water level. Obviously power shovels can not be operated where material is removed from below water level; likewise dredges can not be used in dry excavation.

Power shovels, drag-line excavators, drag or slack line scrapers, or a limited application of hydraulic equipment may be used in dry pits. The wet pit may employ the drag-line excavator and drag scraper but not the power shovel except for stripping. Hydraulic equipment is employed in wet pits as an accessory to some other method but not as a producing medium (8). In addition, wet pits may use the various types of dredges.

The same discussion applies as to the necessity for stripping pits as for banks. Heavy clay ordinarily will require stripping ahead of production from dry pits. If the clay is relatively thin it may be caved and removed with the gravel for separation at the plant. Heavy overburden may be caved and removed with the gravel in wet pits because in doing so the material is prewashed to an even greater extent than in hydraulicking bank deposits.

Where the overburden is thin and of a sandy nature it may at times be disregarded in both wet and dry operations. If it is of a high ratio compared to the gravel it may be necessary to strip in either type of operation. Between these two extremes there lie a variety of conditions which require careful scrutiny. For instance suppose a deposit contains 30 feet of gravel below 10 feet of clay subsoil, and the water level lies at about the midpoint of the gravel. To operate such a deposit dry only 15 feet of gravel could be recovered and that only after the removal of 10 feet of clay. To excavate gravel and overburden together dry, under these conditions, would entail an almost prohibitory load on the washing plant. By operating the deposit as a wet pit and caving the overburden, the whole 30 feet of gravel may be recovered. It is truc that caving the clay will entail more thorough washing in the plant than if it were stripped off first, but the preliminary washing received by caving into the water will greatly reduce this plant duty. The added plant expense may be more than offset by the saving in stripping cost.

Now suppose the ground-water level was only 5 feet above the bottom of the gravel. Operating dry, 25 feet of gravel could be removed for 10 feet of stripping. While this would entail a rather heavy stripping expense, it might not be prohibitory. If no stripping were done, the washing plant would have to remove 40 per cent of the material coming to it. This would constitute a heavy load on the plant. To operate wet there would be only 5 feet of water in which to float dredging equipment. Such a depth, while possibly not prohibitively shallow, is nevertheless verging close upon that state (40). In any case, to cave 10 feet of stripping and 25 feet of gravel into 5 feet of water would offer doubtful economy in preliminary washing. The probable solution in this case would be preliminary stripping, followed by excavation with drag line or drag scraper, with overburden to be cast to the excavated pit.

In case the ground-water line were only 5 feet below the top of the gravel it would be out of the question to strip 10 feet of overburden for 5 feet of gravel in a dry pit. The solution would obviously be a wet pit operated either by drag line, drag scraper, or dredge. Hydraulic methods for either stripping or production have had little application to gravel-pit operations. Because the desired material is below the surrounding land surface, any water brought into the pit for hydraulicking must be pumped out again. While this system is in use in recovering pebble phosphate, it has not been widely used in gravel production.

The physical characteristics of the deposit itself will also have considerable bearing on the selection of methods. A pit deposit containing large quantities of clay should be worked wet, other considerations being equal. The degree of cementation existing between gravel particles or in lenses may change the choice from a pump dredge to a dipper or ladder dredge (35). Also a high percentage of bowlders in the deposit may prohibit the use of a pump dredge or even of a ladder dredge (57).

Pit deposits are invariably worked in horizintal slices. This applies whether the pit is operated dry or wet. However, the method of operation of the horizontal slice or bench may be almost as varied as the equipment available.

In the matter of transfer of material from working face to plant, conditions in pits differ from those in banks in that all material must be elevated. This does not necessarily require the use of different transportation equipment but rather requires the expenditure of more power in lifting material from pit floor to plant level.

From these few conditions, it will be seen that the first problem to be solved in pit operations is whether they shall be operated wet or dry. The next problem is to select the type of equipment that shall be used. With these two problems decided the development method may be laid out.

Dry Pits

The plan of development for a dry pit will depend upon the type of equipment to be used in excavation. The material must, in all cases, be elevated from the pit bottom to the ground level. In shovel excavation the material is elevated by transportation equipment, but drag-line excavators or drag scrapers may themselves be the elevating units. Shovels operate on a working floor below the bank being excavated, so that development designed for this type of equipment must provide for access to and egress from a working level below the original surface. Drag-line excavators or drag scrapers, on the other hand, operate from the surface, or the top of the gravel after stripping. With them the original surface is used for haulage and it is not necessary to develop a lower working level except where the thickness of the deposit requires excavation in multiple benches; then elevation of pit material to surface requires some means of transportation besides the digging equipment used. Installation of transportation equipment and planning for its operation on other than the top bench becomes a problem of operation rather than development and will be discussed as such.

The study of dry-pit development will then be confined to the initial preparation of single-bench operations or to the first of a series of multiple benches.

For shovel operation the pit may be entered by either a straight or curved descending thoroughcut. The length of the entering thoroughcut will depend upon the distance of the working level below the ground surface and the grade required by the haulage equipment. For example, in hauling gravel from pit to plant by locomotive and cars, ordinarily track grades are kept below 5 per cent, and 3 per cent is usually considered a maximum for permanent tracks. This means that a thoroughcut on a 3 per cent grade entering a deposit of gravel 30 feet thick lying under 10 feet of overburden must be 1,333 feet long before it reaches the bottom of the gravel (see fig. 6). At 5 per cent the cut must be 800 feet long. If auto trucks are used, the grades may be increased to 10 per cent or even 15 per cent for short distances. This would shorten the thoroughcut to 400 feet. Many operators use conveyor belts to elevate material from the pit floor (39). These may be operated on grades up to 20° or 35 per cent, thus shortening the thoroughcut in the example to a little more than 100 feet. At other plants material is elevated by cars hoisted up inclines (48) (50), by bucket elevators, or by pumps. In these cases the grade may be increased until it is nearly vertical, depending upon lo conditions. With these maximum grades the entering thoroughcut is driven at as steep an angle as is consistent with good operation of the digging and haulage equipment used in development. The permanent haulage installation is then constructed over the side of the bank and not necessarily in the original opening thoroughcut. In some instances vertical lifts are used which employ skips operating in balance; these, of course, do not use the entering thoroughcut as an avenue of egress. However, the entering cut is required in all cases for access of the digging equipment and transportation of supplies, so that development thoroughcuts must be driven between grade limits of from 3 to 10 per cent, depending upon whether cars or trucks are used for carriers.

Owing to the many variables involved in determining the length and grade of thoroughcuts entering pits, it is difficult to analyze specific examples that will be representative of other than purely local conditions.

Some general statements and specific comparisons may be used to illustrate the effect of haulage grade upon development cost.

Referring to Figure 6, we find the following quantities of materials to be moved, if the gravel deposit is 30 feet thick below 10 feet of overburden and the shovel cut is 50 feet wide at grade with 45° slopes.

Grade, per cent	Length of cut, feet	Overburden, cubic yards	Gravel, cubic yards
3	1,333	36,828	38,880
5	800	22,100	23,333
10	400	11,234	11,300

If the cost per cubic yard for digging and removal is 20 cents for the overburden and 25 cents for the gravel, the entry thoroughcut will cost $17,085.60 for a 3 per cent grade, $8,253.25 for a 5 per cent grade and $5,071.80 for a 10 per cent grade. Thus the 3 per cent grade will cost twice that of a thoroughcut on a 5 per cent grade and over 3-1/3 times that of a 10 per cent grade, other conditions being equal. It is evident then that, where possible, the shorter the entry thoroughcut is made, the less expense and time will be involved in development.

The area of the owned or leased property necessary to accommodate an opening thoroughcut must be considered. In the example cited a 3 per cent grade 1,333 feet long would require the entire width of a square 40-acre plot. Unless additional area could be obtained, the grade would have to be steepened, and even then haulage curves approaching the grade must be of small radius.

The development procedure for a straight opening thoroughcut for a dry pit may follow the plans shown for banks in Figure 2A, B, and C. The thoroughcut itself, however, will be driven on whatever grade is decided upon and not carried level, as into a bank.

Where space is lacking for a long, straight thoroughcut, as in the 40-acre plot previously noted, the entering cut may be curved and descend to the working level in a spiral. Stripping cuts will be similar in this case to Figure 3A, B, and C, except that they will follow the same curve as the thoroughcut. All overburden must be hauled to the site selected for the dump. Where the topography is flat this usually requires the elevation of the dump track, which means pushing the loaded cars up an incline to obtain dumping height.

If drag-line excavators are used for stripping and are followed by shovels for production, the development procedure will be similar to that for shovel stripping. Provision may be made later for casting overburden to the excavated pit, provided the equipment has sufficient reach.

In some instances convertible shovels have been used in thin overburden. The shovel is first equipped with a drag scraper and scrapes the overburden back from the edge of the pit to a windrow parallel with the pit. When sufficient material is collected in this manner, the drag scraper equipment is removed and the dipper installed. The shovel then proceeds to load the windrow into haulage equipment.

If drag-line excavators are used both to strip and to dig gravel the only development necessary is the stripping and excavation of an initial cut either straight or curved, as desired (12). The overburden from this cut may be piled to one side and the gravel loaded on the surface on the other side. Returning on the second cut the drag line will cast the overburden previously removed, together with the new stripping, to the excavated pit formed by the first cut.

If the decision is to use a drag scraper it is usually set up so that material from the initial fan-shaped excavation can be delivered directly to the top of the treatment plant, thus eliminating transportation equipment (20). The scraper will be used first to strip the area to be excavated. For this purpose provision will be made at the delivery end for dumping overburden into cars in which it may be hauled to the dump. Development in this case consists of stripping the area which can be reached by the scraper. This procedure, however, may be modified by stripping only a portion of the reachable area. The scraper is then used to remove the gravel from this small area. When this is excavated the scraper is extended and strips over a wider arc, dumping the overburden into the excavated pit (12). Some contamination will occur where the overburden from the second stripping cut is dragged over the bank of the gravel cut. This may be minimized by using a closed scraper on a slack-line cable. By this means the track cable may be tightened and the scraper lifted as it nears the edge of the pit. It can then dump clear of the gravel bank. If two scrapers are available one may be utilized to strip new ground to the excavated area of the working gravel pit in which the second scraper is producing gravel.

If the deposit is so situated that there is sufficient slope to carry sluices from the top of the gravel to permanent dumps and there is water available at sufficient elevation to provide the necessary head, hydraulic methods may be used to strip a pit deposit (17), in the same manner as described for bank deposits.

By sluicing to a centrally located sump the gravel itself may be hydraulicked to the sump and pumped from there to the plant. This practice is common in the phosphate deposits of Florida. The drag scraper has found its greatest development in the same field.

Wet Pits

The operation of a wet sand and gravel pit involves the removal of material from below the surface of ground water. Many wet pits were originally started as dry excavations. Others have resulted from the extension of marine operations into land beyond the submerged area. A few have been started from previously existing ponds or lakes (52). In those operations originally started as dry pits the dry excavation itself constitutes the development step (44)(55). In some this dry operation may have been continued for years and wet methods resorted to only after exhaustion of material above the level of ground water. Wet pits started from existing ponds or lakes seldom require development as defined. The equipment is installed and digging begins at the shore or bed of the body of water.

Development designed for the operation of wet pits in locations containing no natural body of surface water involves the opening of an initial hole or pit of sufficient size to accommodate the operating equipment in prosecuting systematic excavation. Where overburden is present it may be necessary to remove it from the initial opening, but once excavation is started the necessity for stripping will depend upon the rate of flow and quantity of ground water and the relation of its level with respect to the gravel bed. With favorable water conditions stripping may be abandoned in many deposits which if worked dry would require considerable expense for this item (21)(26). On the other hand, it must not be inferred that the mere change from dry to wet methods obviates the necessity for stripping in all cases (42)(48)(65). No definite rule can be established in this regard because of the influence of a number of local factors. The character of the overburden itself varies widely in different localities. Some sandy loams even of considerable thickness disintegrate readily upon simple immersion in water. The same is true of some sandy clays. Other deposits of clay are so constituted that they break up little if any in water unless violently agitated. Even then some types of clay do not break up entirely but form balls which have a tendency to collect gravel and sand coming in contact with them.

A general rule which may be followed in caving overburden to wet pits is that there must be a depth of water at least equal to the thickness of overburden and a subsurface flow sufficient to maintain a constant water level in the pit.

The position of the water level with respect to the gravel deposit has been already discussed and need not be further elaborated here except to repeat that conditions in each deposit must be carefully studied before the method of operation is finally decided upon.

In the operation of wet pits, two distinct types of equipment are available, land and floating. Land equipment may be either a drag or slack line scraper or drag-line excavator. Either unit operates from the land surface adjacent to the pit. Floating equipment, on the other hand, operates from the water in the pit and may consist of either of several types of dredges. among these may be enumerated in the order of preference, judged by the number of installations, the pump, clamshell, ladder, and dipper dredge.

Development of wet pits for either land or floating equipment may be an extensive proceeding or one of very minor importance. The opening of a pit from existing ponds or previous marine operations by floating equipment requires little development as such. Likewise the opening of wet pits by land equipment in the absence of natural bodies of water may require little preliminary preparation. On the other hand, the opening of a wet pit for floating equipment in deposits where no natural body of water exists may require considerable development ahead of actual sustained production. In opening such deposits obviously the initial hole or pit must be dug by some other type of equipment than a dredge (43)(47).

If preliminary prospecting and exploration has shown land equipment to be the most economical under local conditions, either the shovel, drag line, or scraper may be used to start the work. Either of the last two can be used to dig down through the material lying above water level and continue to the bottom of the gravel or to the economic limit, in one operation (31). Development is then limited to the removal of overburden from the first cut. Where the overburden is thin or sandy even this removal may be dispensed with and all material from the surface down may be sent direct to the washing plant. When the overburden is thick or composed of clay it will be preferable to strip a small area, casting the material to temporary dumps on the surface and later recasting the dumps to the pit after removal of the gravel (29)(65). The extent of this initial stripping will depend upon the size of the hole necessary to start systematic production. This in turn will depend upon the thickness of the overburden and the underlying gravel. With a low water level and limited quantity of water the initial hole should be of such a size that no caving of overburden is required until the bottom of the gravel or the economic depth has been reached. With higher water and a sufficient quantity of it available the overburden may be caved sooner.

In some cases it is difficult to know just where this dividing line must be drawn. If there is present an independent source of clean wash water the preliminary immersion of the overburden in even an insufficient quantity of pit water may be utilized as a first washing to be followed by further washing in the plant. The determining factor will be the relation between the cost of stripping on the one hand and the increased cost of final washing in the plant on the other.

If it is decided that the overburden must be stripped ahead of production the development scheme may be carried out along the same lines as for dry pits, using either shovels, drag lines, or scrapers. Unless for some reason it is economically advisable to strip a large initial area ahead of gravel excavation, shovels will seldom be employed because of the expense of hauling overburden to waste dumps. Both the drag line and scraper can be used to strip and dig gravel intermittently, casting the overburden to the excavated pit.

Where extensive preliminary stripping is not necessary the development scheme for land equipment becomes incidental to the production plan.

Development for dredge equipment is done in different ways. If drag lines are available the initial pit may be dug by them until sufficiently large to float the dredge. The same is true if cableway scrapers are available. Without either of these units a shovel or horse or tractor drawn scrapers may be used to dig the starting pit down to water level. From here on a pump is sometimes set on the gravel with the suction line laid in a hand-dug sump. This sump is enlarged by the pump suction to the limit of its reach, and the pump is then mounted on a raft or small scow. By this means the sump may be enlarged to accommodate the dredge itself. This procedure provides a good method of testing the adequacy of the flow of subsurface water for subsequent pump dredging. By carefully gaging the water level in the small pit while the temporary pump is operating and calculating the fall, if any, against the capacity of the pump the flow may be ascertained.

With few exceptions the operation of wet pits requires some type of transportation equipment between pit and plant. Drag lines usually load cars spotted on tracks laid on the original land surface. In a few instances auto trucks have replaced locomotives and cars.

A frequent exception to the preceding statement is in the use of drag or slack line scrapers. In small operations the head tower of the scraper is usually set adjacent to or built integral with the screening plant structure. This is also the case in many large capacity plants using this type of excavator. When the scraper has exhausted the gravel within economic reach from its initial set up, a second unit is often installed to dig further afield and the first unit is used to transfer material from the digger to the plant.

Transportation from wet pits using land equipment therefore has a minor influence on the development plan. At most, it must provide for surface hauling from pit to plant. There is no necessity for the digging of entry thorough-cuts as in dry-pit operations.

Transportation from floating equipment to plant may be varied. Pump dredges customarily deliver material through pipe lines for short distances direct to the plant (36). For longer hauls floating barges are used. Clamshell dredges at times dump into floating hoppers from which pumps deliver the material to the plant. More often, however, they dump to barges. Ladder and dipper dredges almost invariably load barges for transfer to plant. Development for floating equipment is not materially influenced by the transportation method used.

It will be seen from the preceding discussion that development in its restricted definition plays a rather minor rôle in the preparation for wet-pit operations. In its broader interpretation, which would include the selection of the method of operation and the type of equipment to be used, prospecting and exploration play a much more important rôle. Treatment of the subject in its broader aspect, however, comes more logically under the head of excavation and will be discussed in a circular on that subject.

No illustrative examples have been given of wet pit development costs because of the extremely varied conditions met with in different localities. It is felt that discussion of any detailed set of conditions would only serve to confuse the issue when applied to another locality.

MARINE DEPOSITS

In marine deposits development is again of minor importance. In fact, in only a few instances is any preparation of the deposit desirable or possible. Except for some river bars, the material recovered from marine deposits is submerged in natural bodies of water. In all cases the sand and gravel are recovered from beneath the water level and no stripping is necessary. The character of the material in the deposit has an important bearing on the type of equipment that should be used in marine deposits, but this subject will be discussed in a subsequent circular.

River Deposits

River deposits comprise sand and gravel in the form of bars and small islands or the bed of the river itself. Such deposits may be either of two

Original from THE OHIO STATE UNIVERSITY

types. They may have been laid down in their present position at some earlier stage of the river's evolution where they have remained intact except for minor changes caused by variations in the current, or they may be the result of present-day action of the river currents. Many rivers in former geologic time have been transporters of sand and gravel but have long since ceased to be such (10). In these, gravel deposits are often covered by several feet of fine mud or silt or other débris brought down by floods ([illegible]). No replenishment of sand and gravel as such takes place, however, owing to the exhaustion of supplies upstream. Such deposits can be excavated once only.

In those streams which are at the present-time carriers of sand and gravel many operators have set up plants which dig over the same area year after year. The river itself in spring floods brings down fresh material and fills in the excavation of the previous year (45)(46).

In order to avoid periodic deposits of silt and débris in gravel beds in the older rivers, some operators have deflected river currents by building jetties or dams, thus protecting the site of their excavation from contamination (56). In other cases, by the same means, river currents have been made to deposit material in excavated areas and not spread their burden over sections out of reach of existing stationary equipment.

Such deflection of river currents is properly development of river deposits and is the only instance in which the author can point to development as desirable or possible for marine deposits.

In some instances, it is true that dredging equipment is used to open channels through barren river beds to reach commercial bars, and this work also should be classed as development. Such operations are so erratic and localized that they are without the field of discussion in a general paper such as this.

Lake and Ocean Deposits

Strictly speaking, there is no such thing as development of lake and ocean deposits. This type of deposit is located by prospecting and exploration, usually carried on by the dredge itself. When the deposit is found, the dredge is placed above it and starts producing.

Development applied in its broader sense to these types of deposits would cover a study of preliminary prospecting and economic conditions for the purpose of determining the type of dredge to be used (61)(62). This can be better discussed under excavation and will be left for the paper on that subject.

TYPICAL EXAMPLES OF DEVELOPMENT METHODS

A reader searching through publications in the technical press or books can not help noting the scarcity of information regarding the details of development of sand and gravel plants. In only a very few instances has the author been able to locate other than extremely cursory reference to this subject. The attached bibliography gives a few instances in which development methods are recorded indirectly in descriptions of gravel operations. These have been referred to throughout the text and a few are briefly abstracted in the following paragraphs.

Seaboard Sand & Gravel Co., Port Jefferson, N. Y. (1)

The Seaboard Sand & Gravel Co. decided in favor of the pump dredge in preference to the power shovel because of lower operating costs. The property was developed by starting the dredge in the harbor and causing it to cut its way into the land deposit. By this means gravel could be recovered below high-water mark which would be beyond the reach of the shovel.

Ohio River Sand Co., Louisville, Ky. (2)

In the early operation of the Ohio River Sand Co. bowlders from the shallow parts of the river were collected by hand. Development of the working method has involved the use of various kinds of equipment, from clamshell derricks mounted on barges, and pump dredges, to the present ladder-type dredges. No actual development of the property is necessary since the dredge digs gravel from river bars as found during exploration by the dredge itself.

Menantico Sand & Gravel Co., Millville, N. J. (3)

The Menantico Sand & Gravel Co. property was developed first for operation by a clamshell derrick mounted on railway trucks. With this equipment an inland pond was dug in which the present pump dredge was later installed. Stripping 0 to 3 feet of loam overburden by clamshell derrick and casting the material into the excavated pond cost $0.012 per ton of sand and gravel produced from a deposit averaging 25 feet thick. This cost is divided as follows: Labor $0.008; superintendence, $0.002; fuel, $0.001; and supplies, $0.001.

East Texas Gravel Co., Bois d'Arc, Tex. (4)

A portable drag line was set up on the property of the East Texas Gravel Co., which started development by stripping the overburden and casting it to one side on the surface. The same machine is used to dig gravel. As the excavation increased sufficiently in size the overburden was cast to the pit from which the gravel had been removed. Development consisted of simply digging the initial hole. Digging and casting overburden to the excavated pit cost $0.059 per ton of sand and gravel, divided as follows: Labor, $0.025; supervision, $0.002; fuel, $0.010; supplies, $0.022. In this case the overburden was clay averaging 10 feet thick covering gravel averaging 14 feet thick.

Original from THE OHIO STATE UNIVERSITY

Consolidated Rock Products Co., Durbin, Calif. (5)

The Durbin plant of the Consolidated Rock Products Co. operates on an alluvial-fan deposit formed by the San Gabriel River. The material as shown by test pits, wells, and drill holes is of fairly uniform gradation, and increases in particle size at the river canyon. The water level is 110 feet below the surface. The property was developed as a dry pit by equipment working from different levels. The faces are carried curved or crescent shaped and switchbacks are used on haulage tracks. Eventually underwater equipment will be employed when the ground-water level is reached.

Fort Worth Sand & Gravel Co., Fort Worth, Tex. (6)

The gravel deposits at Fort Worth consist of two distinct geologic formations and in consequence development was planned whereby both types could be exploited and the material mixed or treated separately as desired. Because of the proximity of ground water to the surface and the shallow depth of the gravel, the wet-pit method of operation was necessary. Drag lines were installed because there was not sufficient dependable water for a pump dredge. The property was developed for intermittent stripping and excavation by the same equipment. Overburden is removed and cast to the excavated pit by the same drag line that digs gravel.

The cost is $0.0590 per ton of sand and gravel, divided as follows: Labor, $0.0323; supervision, $0.0123; fuel, $0.0034; and supplies, $0.0110. The overburden consists of clay averaging 5 feet in thickness and covers gravel averaging 16 feet in depth, about 14 feet of which is submerged below ground-water level.

Portland Gravel Co., Portland, Oreg. (7)

The Portland Gravel Co. operates a clamshell dredge in recovering gravel from the bed of the Williamette River and a pump dredge in digging sand from the Columbia River. The bed of the Williamette River has been dug over in many places and as a result consists of a series of potholes which have been filled with oversize bowlders, fine sand, sunken logs, and debris from up river points. Because of this condition, it was decided that the clamshell type of dredge would be the most economical. Conditions are different on the Columbia River and a pump dredge is most advantageous for recovering sand there. Development by this company has consisted of a careful study of the physical conditions and selecting equipment suited to them.

Ward Sand & Gravel Co., Oxford, Mich. (8)

The gravel deposits at Oxford show evidence of being outwash plains resulting from the flow of fluvioglacial waters over terminal moraines. The property contains much gravel both above and below permanent water level. Because of the quality and depth of the gravel below water the wet-pit method of operation is used. The deposit was first opened with slack-line cableways. When a sufficiently large pit was available a dredge of unique design was installed which operated on the principle of a water ejector and pumped material to the washing plant. Later on, barges were substituted for pipe lines for delivery to the plant. Development here has consisted largely of designing dredging equipment to suit local conditions.

J. K. Davison & Bros., Pittsburgh, Pa. (9)

The Davison Co. recover their material wholly from river bars, where no development is necessary. The dredge does its own prospecting and when a suitable bar is found production is started at once.

Dallas Washed & Screened Gravel Co., Dallas, Tex. (10)

The Dallas Washed & Screened Gravel Co. developed a comparatively shallow gravel deposit below heavy overburden with the ground-water level submerging about half the gravel. Early operations removed the gravel above water level. Later drag lines were installed and they continue to be used. Overburden is stripped by one drag line and cast to the pit dug in the gravel by a second drag line. Removing an average of 7 feet of clay from 12 feet of overburden cost $0.031 per ton of sand and gravel.

BIBLIOGRAPHY

Publications of the U. S. Bureau of Mines

1. Dana, Anderson. Methods and costs of mining and preparing gravel and sand for market at the plant of the Seaboard Sand & Gravel Corporation. Inf. Circ. 6592, 1932, 12 pp.

2. Duffy, J. Hamilton. Method and cost of dredging sand and gravel by the Ohio River Sand Co. Inf. Circ. 6421, 1931, 17 pp.

3. Haddow, Hugh, jr. Mining, treatment methods, and costs, Menantico Sand & Gravel Co. Inf. Circ. 6420, 1931, 11 pp.

4. Hyde, Walter W. Mining, treatment methods, and costs at the East Texas Gravel Co.'s deposits. Inf. Circ. 6537, 1931, 7 pp.

5. Jumper, Harry D. Mining, treatment methods, and costs, Consolidated Rock Products Co. (Durbin plant), Calif. Inf. Circ. 6607, 1933.

6. Popplewell, Thos. E. Mining methods and costs at the Hartspur Pit of the Fort Worth Sand & Gravel Co. Inf. Circ. 6652, 1932, 12 pp.

7. Puariea, Howard F. Method and cost of dredging sand and gravel, Portland Gravel Co. Inf. Circ. 6626, 1932, 7 pp.

8. Ward, F. L. Methods and costs of mining and preparing sand and gravel at the plant of the Ward Sand and Gravel Co. Inf. Circ. 6580, 1932, 16 pp.

9. Williamson, Geo. H. Sand and gravel dredging methods and costs of J. K. Davison & Bro. Inf. Circ. 6582, 1932, 10 pp.

10. Windrow, R. L. Methods and costs of mining and preparing sand and gravel at the Cloudy plant of the Dallas Washed & Screened Gravel Co. Inf. Circ. 6581, 1932, 10 pp.

Pit and Quarry

11. Cableway spans unnavigable portion of river to reclaim aggregates. Vol. 22, No. 9, July 29, 1931, p. 43.

12. Collins, Thos. L. American Aggregates operates two strictly modern plants at Oxford, Mich. Vol. 19, No. 3, Nov. 6, 1929, p. 57.

13. Concrete Materials Corp. produces washed sand and gravel at Clarksville, Iowa. Vol. 19, No. 3, Nov. 6, 1929, p. 63.

14. Conglomerate gravel compels producer to abandon hydraulic dredge. Vol. 20, No. 13, Sept. 24, 1930, p. 35.

15. Gravel dredged from lake processed at six shore plants in Buffalo. Vol. 21, No. 13, Mar. 25, 1931, p. 35.

16. Hauer, D. J. The operation of the Dry Harbor Sand & Gravel Corp. Vol. 18, No. 2, Apr. 24, 1929, p. 40.

17. Lincoln, F. C. Pioneer Sand & Gravel Co., Steilacoom, Wash. Vol. 19, No. 12, Mar. 12, 1930, p. 61.

18. Massey, Geo. B. Hydraulic dredge operates successfully in plant of Coogan Gravel Co. Vol. 18, No. 11, July 28, 1929, p. 51.

19. Michigan gravel plant's method of excavation changed to meet variation in deposit. Vol. 19, No. 13, Mar. 26, 1932, p. 59.

20. New sand and gravel plant designed to meet present market demand. Vol. 23, No. 4, Nov. 18, 1931, p. 41.

21. Rapides Gravel Co. successfully meets overburden problem by hydraulic dredging. Vol. 18, No. 8, July 17, 1929, p. 83.

22. Sloan, Harry. Pioneer Sand Co. has unique operation in turbulent Missouri River. Vol. 18, No. 13, Sept. 25, 1929, p. 47.

23. Sonntag, C. H. Economics of plant location. Vol. 18, No. 2, Apr. 24, 1929, p. 69.

24. Strips in winter, excavates gravel in summer with same machine. Vol. 21, No. 2, Oct. 22, 1930, p. 27.

25. Stripping in this quarry is accomplished by a special type of machine. Vol. 18, No. 1, Apr. 10, 1929, p. 50.

26. Trauffer, W. E. Rock Island Sand & Gravel Co. operates modern plant in Mississippi Valley. Vol. 18, No. 11, Aug. 28, 1929, p. 75.

Rock Products

27. A mountainside sand and gravel operation. Vol. 33, No. 4, Feb. 15, 1930, p. 49.

28. A new gravel plant in the southwestern part of New York State. Vol. 31, No. 25, Dec. 8, 1928, p. 46.

29. An extraordinary Texas sand and gravel operation. Vol. 32, No. 6, Mar. 16, 1929, p. 79.

30. An outstanding new sand and gravel plant. Vol. 35, No. 4, Feb. 27, 1932, p. 17.

31. Arizona's largest worked gravel plant. Vol. 32, No. 21, Oct. 21, 1929, p. 69.

32. Australian sand plant. Vol. 32, No. 8, Apr. 13, 1929, p. 85.

33. Butter, R. C. Making sand and gravel down in "Ole Alabam." Vol. 32, No. 19, Sept. 14, 1929, p. 48.

34. Carr, Bradley S. Out of the ordinary 10-inch pump sand and gravel dredge. Vol. 33, No. 15, July 19, 1930, p. 67.

35. Changes and developments in the gravel industry at Knoxville. Vol. 33, No. 15, July 19, 1930, p. 55.

36. Crushed stone producer builds sand plant. Vol. 33, No. 21, Oct. 11, 1930, p. 41.

37. Daggett, Gordon F. Sand plant developed to help sell crushed stone. Vol. 33, No. 22, Oct. 25, 1930, p. 45.

38. ________________ New Wisconsin gravel plant. Vol. 33, No. 23, Nov. 8, 1930, p. 33.

39. Dodge, G. F. Developments at new California sand and gravel plants. Vol. 35, No. 19, Sept. 24, 1932, p. 15.

40. Earnshaw, Geo. M. Small sand and gravel pumping operation shows originality. Vol. 33, No. 20, Sept. 27, 1930, p. 43.

41. Extra measures insure clean gravel. Vol. 34, No. 18, Aug. 29, 1928, p. 44.

42. Fitch, H. M. Sand and gravel plants along the Ill.-Wis. State line. Vol. 31, No. 24, Nov. 24, 1928, p. 47.

43. From shovel to dredge excavation after year's operation. Vol. 35, No. 7, Apr. 9, 1932, p. 17.

44. Goodwin, R. A. Montana 500 cubic yard gravel operation. Vol. 34, No. 17, Aug. 15, 1931, p. 44.

45. Hatch, Jas. N. Typical California gravel operation. Vol. 31, No. 7, Mar. 31, 1928, p. 34.

46. Haworth, Erasmus. Sand pumping at Lawrence, Kansas. Vol. 31, No. 13, June 23, 1928, p. 60.

47. Illinois gravel producer makes changes. Vol. 35, No. 20, Oct. 8, 1932, p. 14.

48. Indianapolis plant of American Aggregates. Vol. 32, No. 20, Sept. 28, 1929, p. 57.

49. Lamar, J. E. Western Indiana Gravel Co. dredges cemented flint gravel. Vol. 32, No. 7, Mar. 30, 1929, p. 71.

50. Miamiville plant of American Aggregates Corp. Vol. 32, No. 11, May 25, 1929, p. 34.

51. New All-Steel gravel plant with novel features. Vol. 32, No. 13, June 22, 1929, p. 34.

52. New dredging operation in Chicago's metropolitan district. Vol. 31, No. 20, Sept. 29, 1928, p. 34.

53. New gravel plant completed in the Cleveland district. Vol. 32, No. 3, Feb. 2, 1929, p. 34.

54. New Paul Ales Plant. Vol. 32, No. 17, Aug. 17, 1929, p. 48.

55. New sand and gravel operation for Philadelphia territory. Vol. 33, No. 10, May 10, 1930, p. 49.

56. Novel sand and gravel transportation. Vol. 30, No. 2, Jan. 18, 1930, p. 25.

57. One of the world's largest gravel plants. Vol. 33, No. 14, July 5, 1930, p. 41.

58. Recent applications of cable excavators at gravel plants. Vol. 33, No. 18, Aug. 30, 1930, p. 58.

59. Redding, L. E. An unusual sand and gravel plant. Vol. 32, No. 1, Jan. 5, 1929, p. 38.

60. Sand and gravel developments at Steilacoom, Wash. Vol. 33, No. 6, Mar. 15, 1930, p. 54.

61. Seagoing sand and gravel plant. Vol. 32, No. 23, No. 9, 1929, p. 62.

62. Shaw, Edmund. Aboard a Lake-Going sand and gravel plant. Vol. 33, No. 19, Sept. 13, 1930, p. 41.

63. ______________ Efficient gravel washing with jigs. Vol. 32, No. 24, Nov. 23, 1929, p. 72.

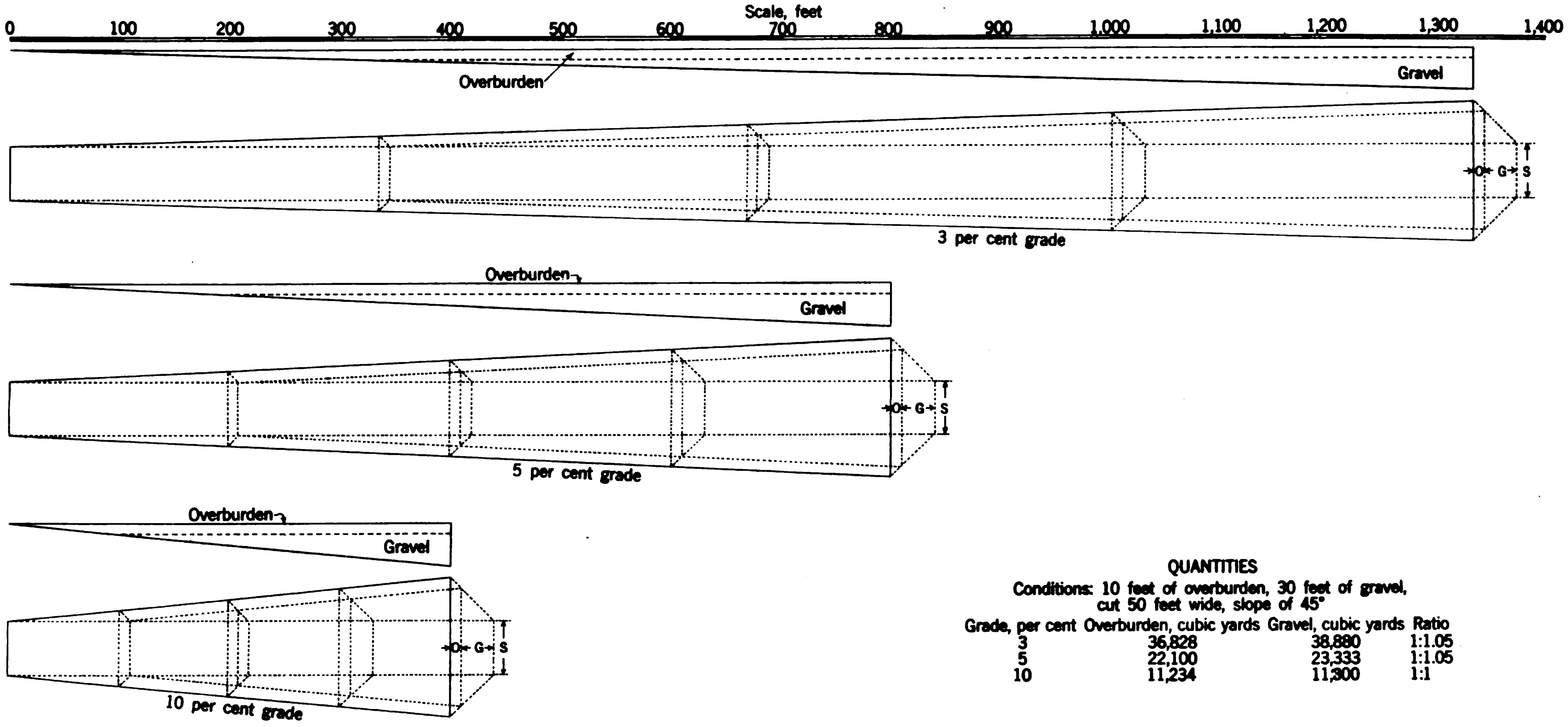
64. Some large-scale sand and gravel operations with movable plants. Vol. 31, No. 9, Apr. 28, 1929, p. 42.

65. Southwestern Ohio sand, gravel and slag activities. Vol. 33, No. 12, June 7, 1930, p. 49.

66. Sturm and Dillard, Circleville, Ohio, gravel plant. Vol. 32, No. 23, Nov. 9, 1929, p. 41.

67. Terre Haute Gravel Co.'s new plant. Vol. 32, No. 16, Aug. 3, 1929, p. 46.

68. Unique sand and gravel dredging operation. Vol. 33, No. 12, June 7, 1930, p. 73.



QUANTITIES

Conditions: 10 feet of overburden, 30 feet of gravel,
cut 50 feet wide, slope of 45°

Grade, per cent	Overburden, cubic yards	Gravel, cubic yards	Ratio
3	36,828	38,880	1:1.05
5	22,100	23,333	1:1.05
10	11,234	11,300	1:1

Figure 6.—Proportions of thoroughcuts of varying lengths